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THE METHODS AND FINDINGS OF EXPERIMENTS ON THE VISUAL DISCRIMINATION OF SHAPE BY ANIMALS

BY

N. S. SUTHERLAND, M.A., D.Phil.
Lecturer in Experimental Psychology in the University of Oxford

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PREFACE

Over the past 50 years, a great many experiments have been performed on the problem of the visual discrimination of shape by animals. The present monograph attempts to review this evidence. I was led to make this attempt because I had already gathered together much material from scattered sources in the course of my own work on this problem. There is little that is original in this review, but by making the data on shape discrimination available in one monograph, it is hoped that the labour of others in gathering and disentangling the evidence may be saved, and possibly some research problems in an important but neglected field will be suggested.

It has not been possible to include all work on the visual discrimination of shapes in the bibliography since much of this work is outside the scope of this review. The main concern is with experiments the primary purpose of which is to throw light on the discriminability of shapes or the properties in terms of which they are discriminated by different species, and it is hoped that the references to such experiments are fairly complete up to the end of 1959, though some more recent papers have been included. In reviewing this body of complex and scattered work, it is certain that some errors will have been introduced: I would welcome any corrections that are offered.

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324267

TABLE OF CONTENTS

Page

INTRODUCTION 1

PART I. METHODOLOGICAL ISSUES

1. GENERAL PRINCIPLES 5
   (1) Learning Scores 5
   (2) Reaction Time Scores 5
   (3) Transfer Tests 6
   (4) Habituation 6
2. SOME EXPERIMENTAL SITUATIONS 7
   (1) The Yerkes-Watson Discrimination Apparatus 7
   (2) The Fields Modification of the Yerkes-Watson Apparatus .. 7
   (3) The Lashley Jumping Stand 8
   (4) Grice Discrimination Box 8
   (5) Wisconsin General Test Apparatus 8
   (6) Shape Discrimination Training in Octopus 9
   (7) Herter's "Training-Prong" Method for Fish 9
   (8) The Stimulus-Object as Reward 9
3. SPECIES OF ANIMAL USED 9
   (1) Availability 10
   (2) Docility 10
   (3) Visual Abilities 10
   (4) Experimental Convenience 11
   (5) Learning Capacity 11
   (6) Pre-existing Preferences 11
   (7) Organism and Situation 12
4. EXPERIMENTAL TECHNIQUES OF TRAINING 13
   (1) Multiple-Choice Discrimination 13
   (2) Two-Choice Discrimination with Multiple Stimuli 14
   (3) Successive versus Simultaneous Discrimination 17
   (4) The Discriminative Response 20
   (5) Control of Other Cues 21
   (6) Control of Preferences.. 24
   (7) Elimination of Transfer Effects 24
   (8) Conspicuousness of Stimuli 24
   (9) Correction versus Non-Correction Method 25
   (10) Rewards and Punishments 26
   (11) Spacing of Trials 28
5. TRANSFER TESTS 28
   (1) Rewards and Punishments 28
   (2) Approach-Avoidance Learning 29

PART II. SURVEY OF EVIDENCE ON SHAPE DISCRIMINATION

1. DISCRIMINATION OF ORIENTATION 32
   (1) Rectangles 32
   (2) Triangles.. 33
   (3) Mirror-Images and 180° Rotations 34
   (4) Miscellaneous 38

Page

2. Discrimination of Form 39
   (1) Triangles and Circles 39
   (2) Triangles and Squares.. 40
   (3) Squares and Circles 42
   (4) Crosses 43
   (5) Miscellaneous Shapes 44
3. The Properties of Shapes Discriminated 46
   (1) Size 46
   (2) Outlines 47
   (3) Background 51
   (4) Change in Relative Brightness of Figure and Background .. 51
   (5) Parts of Figure.. 53
   (6) Internal Distortions of Figure 56
   (7) Distortion of External Parts of Figure 57
   (8) Changes of Orientation of Figure 57
4. Conclusions 58

References 59

Subject Index 67

INTRODUCTION

Since the early years of the present century there have been numerous investigations on problems connected with the visual discrimination of shape by animals. The subject has a curious history. Until the late 1930's it could be said that there were too many experiments insufficiently guided by theory; since that date there have been too many theories insufficiently based on experimental evidence. Early investigators collected data which were relevant to the problem of how animals actually classify visually presented shapes—for example they set themselves to answer such questions as "Can animals discriminate form *per se*?" (Bingham, 1913; Hunter, 1913; Johnson, 1914; Fields, 1932), but experiments were not designed to test specific predictions from theories. In more recent years many experiments involving the visual discrimination of shapes have been undertaken, but they have usually been undertaken in order to solve problems other than that of how shapes are classified by animals. At the same time several theories of the mechanism at work in the classification of shapes have been developed recently (Rashevsky, 1948; Hebb, 1949; Deutsch, 1955; Selfridge, 1956; Uttley, 1956*a*, 1956*b*; Sutherland, 1957*b*, 1960*b*; Dodwell, 1957): many of these theories largely ignore the existing experimental evidence about which shapes animals can readily classify apart and which they readily classify together. This monograph attempts to review experimental work on shape discrimination in so far as it is relevant to the problem of how visually presented shapes are classified by animals. No such comprehensive review has appeared since 1926 (Williams) though there have been recent reviews of the evidence for rats and fish (Munn, 1950; Herter, 1953).

In order to explain the scope and rationale of this monograph it is necessary to specify in more detail what aspect of the problem of how shapes are classified is under consideration here. Essentially the problem is one of how proximal stimuli are classified by the organism: this is the problem of classical psychophysics, but classical psychophysics concentrated on varying simple dimensions of the physical stimulus such as the frequency or intensity of a sound wave. Here we are interested in the question: what are the properties of shapes in terms of which an animal classifies them as the same or as different from one another? At this level findings could be stated as generalisations: we could attempt to correlate a tendency to give the same response to different shapes with some geometrical property shared by the shapes. Since, however, a *property* is usually thought of as being present or absent, whereas shapes resemble one another for a given species to a greater or lesser *degree*, it is more accurate to talk of the *dimensions* along which shapes are analysed. Examples of such dimensions are absolute vertical extent of a shape, vertical extent relative to area, ratio of vertical to horizontal extent, contour relative to area, number of re-entrants: all these dimensions except the last are continuous.

If we knew what were the dimensions analysed by a given species, a further problem would arise, namely, what is the neural mechanism in the brain which analyses the input from the shape in terms of the relevant dimension? Human

beings can identify a triangle as a triangle despite variations in size, shape, orientation, colour, brightness, background, the part of the retina on which it falls, whether it is a filled-in or an outline figure, or whether it is a figure with a continuous or discontinuous outline. The inputs to the nervous system are very different under these different circumstances: at some stage in the nervous system they must be analysed in terms of the dimension of "triangularity," so that despite the variation in input, a common output is given. Ultimately it is the task of psychology to discover what this analysing system is. In order to solve this problem for a given species, however, we must know what are the dimensions along which animals are classifying shapes. To discover this we need a measure of the degree of difficulty which an animal has in reacting differentially to different shapes, i.e. a measure of their *discriminability* for particular species. The latter information gives a measure of the extent to which the members of a given pair of shapes are close to one another on a dimension under analysis, or in neurological terms the extent to which such shapes yield consistently discrete signals in the nervous system of the animal with respect to some analysing system at work. (For a fuller account of this approach to the problem of the classification of visually presented shapes and of some of the difficulties in it *v.* Sutherland, 1959*c*.) The evidence reviewed here will be evidence on the discriminability of shapes and the properties or dimensions in terms of which they are discriminated: such evidence must form the basis for any theory of the classificatory mechanisms at work.

The problem is one which is important and currently neglected. It is important because no theory of behaviour can be complete without taking into account how organisms classify stimuli. Thus most learning theorists ignore the problem of what constitutes the same stimulus for an organism: no matter how much they protest otherwise, they use the word stimulus to mean not the physical stimulus as it affects the organism's receptors, but the stimulus as classified by the organism. Thus Hull (1943), although he uses the phrase "physicalistic stimulus," introduces the postulate of afferent neural interaction which is an acknowledgement that the problem exists but does not constitute a step towards its solution. Statistical learning theorists postulate stimulus elements, but make no attempt to identify them (cf. Estes, 1959). The information theory approach to behaviour cannot deal successfully at the moment with the discriminability of stimuli (Crossman, 1955; Broadbent, 1958). The comparative ethologists have recognized the problem and have begun work upon it: they have attempted to determine the properties of certain sign stimuli in virtue of which the animal reacts, e.g. some gallinaceous birds give a fright reaction to the form ⊣ when it is moving in the direction of the shorter arm (Tinbergen, 1951). Historically the Gestaltists gave fullest recognition to the problem of how complex stimuli are classified, and their question "Why do things look as they do?" may be rephrased as "How do organisms classify the proximal stimulus?"

The present review is concerned with experiments upon one aspect of the general problem of how stimuli are classified, namely with the problem of how shapes are classified by animals. Many recent experiments upon animals involving shape discrimination do not bear upon the problem of discriminability as outlined above. These experiments will not therefore be reviewed here: they include experiments in which the effects of lesions upon shape discrimination are investigated, and experiments in which some aspect of the learning situation other than the discriminability of the shapes themselves has been investigated (e.g. the improvements in learning scores when a number of problems are presented serially, Harlow, 1949).

Two further classes of experiments are excluded which bear more directly on the issue of shape discrimination: (i) Experiments upon the effects of early experience on subsequent performance on discrimination problems. There are several recent reviews of such work (e.g. Beach and Jaynes, 1954; Zuckerman and Rock, 1957). Moreover, such studies attempt to answer the question how do animals *come to classify* shapes in the way that they do and this question is logically independent of the problem of how they do in fact classify them. Even the question of what is the actual mechanism by which an adult animal classifies shapes is logically independent of how that mechanism came into existence, i.e. whether it is the result of genetical or experimental factors (Sutherland, 1959*c*). (ii) Experiments upon the continuity non-continuity dispute are also excluded from this review. Such experiments attempt to answer the question "How is the change from the use of one classificatory mechanism to the use of a different classificatory mechanism effected?": they do not normally throw any light upon what the actual classificatory mechanisms are.

The experiments with which this study will be primarily concerned are those which seek to discover a difference in discriminability between different shapes, and those which attempt to discover the dimensions in terms of which shapes are discriminated. Although such experiments involve learning, the learning is used only as an index of the discriminability of the shapes, and we shall not be concerned with the learning process as such. However, experiments of this kind are not all of equal value since there are many methodological pitfalls in this type of work. In order to have criteria for evaluating results, we shall first enter into some detail on the methodology of experiments on shape discrimination.

Part I of this review is therefore devoted to a review of the methodology of this type of work: as in other areas of psychology, much of the advance made in experimental work on shape recognition has been in improving *methods* of discovery. These methods have still not been sufficiently applied to obtaining the type of data we are here interested in, and some current work does not conform to the methodological principles which will be enunciated. These principles have not previously been examined in detail in relation to work on shape discrimination, and it may be that setting them out in one place will demonstrate the possibility of solving an interesting and important problem, and will lead to greater methodological sophistication in future work in this area. In dealing with methodological questions, it will be necessary to discuss and compare many different types of discrimination learning situations. It is hoped that this systematic comparison of discrimination learning situations will be of interest in its own right, since many of the specific topics considered have been neglected by learning theorists. Learning theorists cast their net so wide that they tend to ignore many of the details of the learning situation, e.g. the exact relationships between stimuli, responses and discriminanda. An attempt will be made here to show that if the details of different discriminatory learning situations are thoroughly analysed, it is possible to show what the animal learns and also to explain systematically and in simple terms why animals learn faster under some conditions than others. This is the only part of this review where the interpretations given are to some extent original. Since some work on brightness discrimination and some studies on human beings are relevant to methodological issues, it will be necessary to consider in Part I some experiments outside the field of shape recognition in animals.

Part II reviews the results of experiments on the discriminability of shapes and the dimensions along which they are discriminated by different species of animal. Work on human beings and on animals with compound eyes is excluded. Human

beings are capable of discriminations of such complexity that results are difficult to interpret, whilst animals with compound eyes classify shapes in very different ways from other animals. Part II deals solely with variations in behaviour due to differences in the actual shapes presented to the animal: all such differences in shapes used will be discussed except where the shapes were varied by rotation around an axis lying in the frontal parallel plane and where the shapes were altered by varying their distance from the animal (experiments on shape and size constancy). In addition, variations due to altering the position of the image on the retina (binocular transfer, etc.) will not be discussed. Considerable emphasis will be given in this part to comparisons between results with different species.

PART I. METHODOLOGICAL ISSUES

1. General Principles

In order to acquire information on the discriminability of different shapes, and upon the properties in terms of which they are being discriminated, it is necessary to ensure that the organism makes differential reactions to the shapes. Four general methods of acquiring information of this sort are outlined below: only methods (1) and (3) have been extensively used in animal work: methods (2) and (4) are included because they may prove useful in the future.

(1) *Learning Scores*

The most commonly used method is to train animals to make differential responses to different shapes, and to use some feature of the series of responses made as a measure of the difficulty of discriminating between the shapes. There are a number of such possible measures: they are (i) The number of errors made before the animal reaches a certain criterion of success (e.g. one can compare the difficulty of learning two different discriminations by considering the number of wrong reactions an animal makes before it gives 19 correct reactions in 20 successive trials). (ii) The number of trials which has to be given before the animal reaches a criterion of success. (iii) The number of errors made over any arbitrarily chosen section of trials (e.g. trials 1–40, or trials 41–100). Although correlation measures between scores computed in these three ways are not normally given, they appear to correlate well: thus Lashley (1938) reports learning scores for 21 different pairs of shapes learned by rats. A rank order correlation (ρ) has been computed by the present writer between his error scores (to a criterion of success) and number of trials to the same criterion for the 21 pairs of shapes, and the correlation coefficient is 0·96 (*v.* also the study cited in the following paragraph, Adams *et al.*, 1954). Since all three scores are ultimately based on the frequency of errors and since the number of errors normally declines smoothly with learning, it is not surprising that the scores computed in these different ways should correlate highly with one another. Which of these scores we use as an index of discriminability will therefore depend on their sensitivity.

(2) *Reaction Time Scores*

For primates (including humans) none of the above measures is suitable for assessing the ease with which different pairs of shapes are discriminated, unless the discriminations are very difficult ones. Thus Harlow (1944*a*) in a series of discrimination tests with test-wise monkeys found that on 80 per cent. of tests the monkeys reached a criterion of 20 correct responses out of the first 25 presentations: when initial learning of a discrimination is as quick as this, error scores or trials to a criterion cease to be sensitive indicators of the difficulty of classifying the stimuli differentially. Again with adult human beings the learning of a simple shape discrimination is immediate. In the case of human beings it is possible to take the reaction time for a given discrimination over a series of trials as a measure of the difficulty of the discrimination. In a recent study (Adams *et al.*, 1954) in which human subjects learned to discriminate between shapes it was found that the correlations between reaction times and trials to a criterion of learning and errors to a criterion of learning were of the order of 0·90: the correlation coefficient between trials to a learning criterion and errors to the same criterion was 0·89. It should be noted that error scores *could* be used in this experiment because the shapes were

complex and thus discrimination was difficult. It seems likely that reaction time would still be a sensitive indicator of discriminability if simpler shapes were used. Thus, Sleight (1952) has used a measure similar to reaction time in an investigation of the discriminability of simple geometric forms: he measured the time taken to sort all examples of any one form from an array containing several different forms. This technique is a promising one for the investigation of shape discrimination in human beings, though it has not yet been employed in a sufficiently systematic way.

(3) *Transfer Tests*

The methods so far discussed merely serve to give us measures of the discriminability of different shapes. The technique of transfer tests supplies information on the dimensions in terms of which shapes are being discriminated. Having trained an animal to react differentially to two shapes, we can substitute different shapes and discover the extent to which the animal classifies the new shapes in the same way as the original ones: if a sufficient variety of new shapes is used, it becomes possible to delimit the dimensions of the original shapes along which they are discriminated. This technique appears first to have been used in 1913 by Bingham but it was not developed systematically until the 1930's (Lashley, 1930; Munn, 1930*c*; Klüver, 1933). Klüver named the method "the method of stimulus equivalence." The use of this method raises a number of problems peculiar to itself of which early investigators were largely unaware, e.g. Coburn (1914) found that a crow's discrimination between a circle and a triangle was unaffected by inversion of the triangle, and on the basis of this Bingham concluded that the crow could discriminate the triangle in any orientation: the evidence does not justify this conclusion since the crow might have been reacting solely to the circle and not to the inverted triangle. The problems of technique and interpretation raised by this method will be discussed more fully below.

(4) *Habituation*

A further possible method of obtaining information on the discriminability of shapes is to make use of the tendency found in animals to explore novel stimulus-objects. Thus, Thompson and Solomon (1954) found that if rats were exposed to a card bearing a triangle for 10 minutes, a group which was exposed to a card bearing vertical striations for a second 10-minute period showed more exploratory behaviour during this time than did a group which was exposed to a card of the same design for both periods. Now it seems highly probable that the bigger the difference in the signals produced in the nervous system by the two cards (i.e. the greater their discriminability), the more time will be spent in exploration during the second period and this might be used as a measure of the discriminability of different pairs of shapes for a given animal. A similar technique was used by Wells and Wells (1956) in an investigation of touch discrimination in the octopus. They presented cylinders with different surfaces to octopuses: when a cylinder is first presented it is seized by one of the arms, taken to the mouth, and eventually rejected. On subsequent presentations of the same cylinder the octopus learns to reject it more speedily and after several trials rejects it without taking it to the mouth. If at this stage a cylinder with a different surface is presented it will again be conveyed to the mouth. It might be possible to measure the tactile discriminability of pairs of cylinders by measuring the saving in number of trials to learn to reject the second. The present writer has undertaken some experiments (unpublished) with octopuses employing a similar technique. It was found that if a shape was presented visually to an octopus it will normally attack it: with repeated presentation it learns not

to attack a given shape. The strength of the tendency to attack a second shape can be measured and the more discriminable the second shape is from the first the greater the tendency to attack the second shape. It will be noticed that this method is not unlike the method of transfer tests. In transfer tests the extent to which a learned reaction to one shape will transfer to another is used to discover what properties of the initial shape were being discriminated. In the present method, the extent to which the extinction (or habituation) of a pre-existing response to one shape will transfer to a second is used to give a measure of the discriminability of the two shapes. One possible advantage of this method which may make it worth pursuing in the future, is that it gives a guide to the way in which the initial shape is classified where that classification is not influenced by the necessity of discriminating the shape from the other shape used in training.

2. Some Experimental Situations

Some of the experimental situations most frequently used in discrimination work with animals will now be briefly described. No effort will be made to describe all the possible variations on these situations, and their advantages and disadvantages will not be discussed in detail in this section. They will be evaluated more thoroughly in the two sections which follow. Munn (1950) has reviewed techniques of training for rats, and Herter (1953) for fishes.

(1) *The Yerkes-Watson Discrimination Apparatus*

The basic form of this apparatus was first introduced by Yerkes in 1907: it is fully described in Yerkes and Watson (1911). Many variations of the apparatus have been used. In its original form, animals were admitted to a choice chamber and had to learn to approach one of two stimuli set in the end wall and separated from one another by a partition. If an animal made a correct choice, it could proceed through a door in the side wall, and then retrace up a corridor to a food chamber in front of the choice chamber: after eating it could be readmitted to the choice chamber. Shock was sometimes used for wrong responses. The stimuli were usually openings cut in the end walls and covered with frosted glass illuminated from behind. This apparatus was never very successful—e.g. Williams (1926) failed completely to teach dogs to discriminate shapes in this situation. In principle the apparatus could be used with most animals.

Fields (1928) criticized the apparatus on three grounds: (i) Discrimination had to take place from a distance determined by the partition, and animals might not be able to accommodate accurately at this distance. (ii) "The general situation was too complicated," and reward was delayed until long after the correct choice had been made. (iii) The apparatus was unnecessarily complex. The reasons for the failure of the Yerkes-Watson apparatus will be examined more closely below.

(2) *The Fields Modification of the Yerkes-Watson Apparatus*

In 1928, Fields modified the Yerkes-Watson apparatus by leaving out the partition, and making the stimuli holes cut in the back wall of the choice chamber. The animal had to learn to go through the correct stimulus hole in order to get to food in a chamber immediately beyond. Although he succeeded in training rats to discriminate in this apparatus (Fields, 1928), he later (Fields, 1929) showed that discrimination had been largely based on kinaesthetic or tactile cues. The apparatus was then further modified by raising the position of the stimulus holes and training the rat to go through a space *beneath* the positive shape. This apparatus had, however, its own defects (*v.* below).

(3) *The Lashley Jumping Stand*

In 1930, Lashley devised a new apparatus for use with the rat which resulted in much more rapid discrimination learning. Rats jumped from a platform to one of two stimulus cards exposed side by side. If the rat jumps to the correct card, the card is knocked down and the animal goes through on to a food platform immediately behind the card; the negative card is fixed in position and if an animal jumps to this card it falls into a net. The bump against the fixed card and the fall into the net act as punishment. The method involves considerable pretraining in which the distance of the jumping platform away from the two holes (later to be filled by the stimulus cards) is gradually increased. In a difficult discrimination the rat may refuse to jump after making a number of mistakes and some experimenters have shocked animals on the jumping platform or resorted to other forms of violence such as tail-tweaking in order to encourage jumping (Fields, 1932). In 1935, Fields modified the Lashley jumping stand by introducing five possible positions which the stimulus cards could occupy instead of two. This may help to eliminate position habits. He later introduced a further modification (1953): he combined five jumping stands serially in such a way that a correct jump on one brought the rat on to the jumping platform of the next stage of the apparatus: the animal did not obtain food until it reached the platform behind the fifth jumping stand. Ladders were provided so that if an animal made a wrong jump at any stage, it could climb out of the net back on to the jumping platform. Fields (1953) gives an interesting list of criteria for the efficiency of a discrimination apparatus, and claims that in terms of at least some of these criteria the five stage jumping stand is more efficient than the one stage (*v.* below).

(4) *Grice Discrimination Box*

This apparatus combines features of the Lashley jumping stand and the Fields modification of the Yerkes-Watson discrimination apparatus. The essential features of the apparatus are a discrimination chamber in which are two doors which the animal can approach: if it pushes against one door it obtains food, the other door is locked and the animal may be shocked for pushing against it or approaching it. Since the door openings are always the same shape the animal cannot learn on the basis of non-visual cues, as in the Fields modification of the Yerkes-Watson discrimination apparatus. An early form of this apparatus was described and used by Munn (1931*b*). Grice (1948*a*) used an essentially similar apparatus, and it has recently been used in a series of experiments by Gibson and her co-workers (Gibson and Walk, 1956; Gibson *et al.*, 1958; Walk *et al.*, 1958, 1959).

(5) *Wisconsin General Test Apparatus*

This apparatus for use with monkeys was developed by Harlow in 1938, and is described in Harlow (1942) and Harlow and Bromer (1938). The monkey is confined in a small cage and is presented with a horizontal tray on one side of the cage. On the tray are placed the stimulus-objects to be discriminated. Under each object is a food well: the well under the correct object is baited. The monkey is trained to respond by reaching through the bars of the cage and picking up one stimulus-object. If it selects the correct object it can obtain food from the well underneath. The tray can be withdrawn out of the monkey's reach after it has made a response. While the tray is being baited between trials, an opaque screen is lowered to prevent the monkey seeing the tray; frequently a one way vision screen is placed between tray and experimenter. Rensch and Altevogt (1953, 1955) have used a similar apparatus with an elephant.

(6) *Shape Discrimination Training in Octopus*

Boycott and Young developed a training situation for *Octopus* which has been extensively used. (For description see Boycott, 1954; Boycott and Young, 1955; Sutherland, 1957*a*). Octopuses are kept in individual tanks. At one end of the tank a pile of bricks is placed to provide a home. The octopus normally sits in its home looking out down the length of the tank. At the other end of the tank the shapes to be discriminated are introduced on the end of a transparent Perspex rod. Shapes are shown singly (successive discrimination training). While in the water, shapes are kept moving through a distance of about 3 cm. three times a second either by hand or by means of a machine (Sutherland, 1957*a*). The octopus is trained to attack the positive shape (i.e. to approach it and grasp it firmly with its arms) by rewarding it for attack with a crab or a piece of sardine, and not to attack the negative shape by punishing it for attack by an electric shock administered by means of two electrodes on the end of a probe.

(7) *Herter's "Training-Prong" Method for Fish*

Herter (1929) devised a method of training fish which has been widely used since with several modifications (for an account of variations on the method *v.* Herter, 1953). Two stimulus plaques are inserted into one end of a tank on the end of rods: the rods attach to the lip of the tank at their upper end. By means of two thin prongs, attached at the top of the rods, a small piece of bait is held just in front of each plaque at the centre of the stimulus inscribed on the plaque. One piece of bait is edible, the other is not—either because it is made of wax of the same shape and colour as the edible bait or because it has been dipped in some evil tasting substance such as quinine or paraffin. In a later modification both stimuli are inscribed on the same plaque and the baits are attached to a "double-prong" fixed to the rod holding the stimulus plaque: with this arrangement both stimuli are lowered into the water with the same movement. In this situation it is necessary to run tests from time to time in which both baits are made the same to ensure that fish have not been learning to discriminate by means of cues emanating from the baits rather than by means of the difference between the two stimuli.

(8) *The Stimulus-Object as Reward*

Some experimenters have used pieces of food cut in different shapes as the stimuli to be discriminated: they arrange that the negative food object be treated in such a way as to render it uneatable either by making it immovable (e.g. by glueing to the floor or covering with glass) or by giving it an unpleasant taste by the addition of a substance like quinine. As in the Herter situation controls are necessary in which both stimulus-objects are made equally edible to ensure that the animal has learned to discriminate between them in virtue of their different shapes. Katz and Revesz (1908), in an experiment with hens, appear to have used this technique first: it has subsequently been used with dogs (McCallister and Berman, 1931) and fish (Maes, 1930). The technique could clearly be adapted for use with most animals.

3. Species of Animal Used

It is interesting to consider why some species and not others have been used in experiments on shape discrimination and also what are the characteristics of the ideal species to use for this type of work. Although behavioural experiments on any species are interesting in their own right, and although one must be wary of generalisation from one species to another, some species may initially be better

for investigating a given function than others just as the physiologists found the giant axone of the squid a useful starting point for the investigation of nervous conduction.

(1) *Availability*

An important determinant of the species of animal used for studies of visual shape discrimination has been the availability of members of different species and the ease with which they can be kept in good health under laboratory conditions. This factor has probably been that chiefly responsible for the number of studies performed on the rat, which on other grounds is not a very suitable animal for experiments on shape recognition.

(2) *Docility*

In selecting an animal, the ease of handling and docility are important factors. No studies of shape recognition have been attempted on the wild rat: the mere presence of a human being is enough to throw it into such a frenzy of rage that it would be almost impossible to train it on any discrimination. Even it if were possible, it would be a poor animal to choose since, if learning is impaired by emotional responses occurring in the training situation, the emotionality of the animal may have so great an effect on learning scores that it completely overshadows any effect due to the difference in discriminability between different shapes. Even with laboratory rats it is necessary to submit them to a period of preliminary handling before placing them in the experimental situation, otherwise the emotionality of different rats will appear as a factor influencing the learning scores (for an experimental demonstration of the importance of "gentling" on subsequent performance *v.* Bernstein, 1957). Thus it is important that the animal should be thoroughly accustomed to the experimental situation before it learns any shape discrimination, and that training should not start before all fear responses in the situation have been extinguished.

(3) *Visual Abilities*

If we want to arrive at the classificatory mechanism being used by an animal in shape discrimination it is perhaps desirable to select a species which is not too complex. It may be that in monkeys the number of possible dimensions along which shapes are analysed is so great that it would be difficult to investigate these dimensions in detail.

There are two further points worth making in connection with the visual ability of the animal selected. The animal must be one with a lens capable of forming a reasonably well defined image on the retina, otherwise all shape recognition may be impossible for it. It should also be of a species whose individual members do not tend to suffer from grave visual defects. The laboratory rat is not particularly suitable by this criterion; Lashley (1938) found that nearly 30 per cent. of his colony suffered from grave lens defects. Only by knowing the focal length of the eye is it possible to decide at what distance from the stimulus objects an animal should be made to discriminate (cf. Fields, 1928).

The second point is that it is preferable to select an animal which customarily uses visual information in learning, rather than one which tends to rely on information acquired through some other sensory modality. The reason for this is that an animal not normally dependent on vision may require much training before it successfully discriminates on the basis of vision. Moreover, since individual animals will vary in the number of trials needed before they start responding in terms of

vision, this variation may conceal differences in error scores due to the difficulty of discriminating different pairs of shapes. Again the rat fails to meet this criterion adequately: thus Fields (1935) suggests that the reason his rats learned a discrimination more quickly in a five hole jumping stand than in a two hole jumping stand may have been that the greater variation in kinaesthetic and other cues in the former apparatus forced the rats to attend to visual cues after fewer trials than in the latter. However, although the rat is a nocturnal animal there is evidence that where visual cues are available it may make more use of them than is sometimes supposed. Thus Tsang (1934) found that peripherally blinded rats averaged 281 errors before reaching a criterion of learning on an elevated maze, whereas normal animals learned with only 75 errors.

(4) *Experimental Convenience*

The animal chosen should be one with which it is possible to ensure that it will see the shapes whenever they are exposed, and that it will see them from the same position. Unless the animal sees the shapes on each trial, learning will be slower, and variability again increased. In addition, if the animal does not always see the shapes from the same distance and direction uncontrolled variations in the retinal size and shape of the figures are introduced, thus contributing a further source of variability. The jumping stand was a most ingenious way of overcoming this difficulty with rats: the smallness of the platform from which the rat jumps ensures that it always sees the shapes from approximately the same distance and direction; and since the jump must be visually guided, the rat is forced to look directly at the shapes. This point is connected with the previous point in so far as an animal which makes much use of vision may very quickly learn which visual elements are relevant in a given situation. Thus in the Wisconsin General Test Apparatus, in which the distance and direction of the shapes are controlled by the bars of the cage, the monkey learns to orientate itself to the screen and, after a series of shape discrimination problems, may come to solve further problems in one trial (Harlow, 1944*a*, 1944*b*, 1949).

(5) *Learning Capacity*

Some animals appear to give innate responses to shapes; while it is possible to investigate the way such shapes are classified by giving transfer tests, it is impossible to verify predictions made from a hypothetical classifying system about the discriminability of different pairs of figures, unless the animal can *learn* a discriminatory response. The extent to which a species will give evidence of learning is of course very closely bound up with motivation: thus any animal we choose must be one whose motivation can be manipulated in such a way as to produce learning.

(6) *Pre-existing Preferences*

Animals with strong innate preferences (or strong preferences based on early learning) for certain shapes are not very suitable for the investigation of shape discriminability. If such strong innate preferences do exist, differences in ease of learning may reflect simply the difficulty of attaching a response to the stimulus as classified and not the difficulty of classifying. Thus, Lashley (1938) found that in a jumping stand his rats manifested a strong preference for horizontal over vertical striations. This may have occurred because in jumping it is advantageous to land on a horizontal surface, and the horizontal striations may have represented such a surface for Lashley's rats. Law (1954) confirmed Lashley's results. He found that if rats were pretrained to select a black card rather than a white, a very strong

preference for horizontal striations was shown; animals pretrained to select white showed a slight preference for vertical striations. Where animals have pre-existing preferences we cannot use learning scores as an index of the discriminability of pairs of shapes. Thus, the rapid learning when horizontal stripes are positive reflects a pre-existing response tendency: the slower learning when vertical stripes are the positive stimulus reflects the difficulty of reversing this response tendency. There is no guarantee that by training half the animals with one stimulus positive and half with the other stimulus positive we can discount the effects of the pre-existing preference, and by using the average of the two groups arrive at an index of the discriminability of the shapes. This would only be possible if it were true that it takes exactly twice as many trials to learn to reverse a discriminative response as it took to learn to make it originally. Once again it appears that rats are not very suitable animals for the sort of work under review.

In many species no adequate tests have yet been made for pre-existing form preferences. Fantz (1957) has demonstrated that new born chicks have a preference for pecking at round objects rather than angular ones. It has been demonstrated that octopuses have pre-existing preferences when shapes are in motion. Sutherland and Muntz (1959) have shown that they prefer shapes moving in the direction of their long axis to shapes moving across their long axis, and that they prefer shapes moving in the direction of their points to shapes moving across the direction of their points. In the octopus these preferences have only a small effect on learning scores. Many fishes seem to prefer jagged forms to compact forms, e.g. a pyramid to a cube (Herter, 1929), a star to a circle or square (Zunini, 1937), a cross to a circle (Herter, 1949) (cf. also Fisher, 1940; Meesters, 1940; Kettner, 1948; Herter, 1950). Such pre-existing preferences seem to affect learning scores in fishes, though full statistical confirmation of this is lacking (Herter, 1949).

(7) *Organism and Situation*

It must be remembered that it is not really possible to discuss an organism's characteristics without reference to the situation in which the organism is placed. It is seldom possible to say "this animal is an unsuitable subject for this purpose" —all we can say is "this animal in this situation is unsuitable for this purpose." It is worth illustrating this by referring to some of the points already made about the characteristics of species. The extent to which an animal relies on visual information is something which varies not merely from species to species but within species from one situation to another: thus the greyling butterfly makes use of colour in its selection of food but not in the control of its courtship behaviour (Tinbergen *et al.*, 1942). Again, although in the jumping stand the rat exhibits a preference for horizontal stripes against vertical ones, Sutherland (1961*a*) has found that in a different learning situation this preference is not manifested.

The difficulty of assigning characteristics to species, except when they are considered in relation to some environmental situation, has important consequences. It is impossible to assess the upper limits of discrimination for a species, at least where the discrimination is one of some degree of complexity and is not limited by peripheral factors (as would appear to be the case with visual acuity in man). The fact that an animal cannot learn a given discrimination in one experimental situation is not evidence that it cannot learn it in any situation. Thus on the basis of experiments performed with rats and raccoons in a modified Yerkes apparatus (1930*a*, 1930*b*) Munn concludes that these animals are incapable of learning to discriminate visual patterns—he writes: "The inability to learn the discriminations was due not to the characteristics of the apparatuses *per se*, but to a deficiency in

the rat's ability to discriminate visual detail": Lashley (1938) was shortly to demonstrate that the discrimination between the shapes Munn used with his rats (a cross and a square) was in fact one of the easiest pattern discriminations for the rat in the jumping stand situation. Yet there is no guarantee that the jumping stand is itself the optimal learning situation for the rat: it would be as misguided to claim that the limits of the rat's capacity for shape discrimination found with the jumping stand represent the upper limit of its capacity as it was to claim that the rat has no capacity for detail vision on the basis of experiments with a modified Yerkes apparatus as used by Munn.

In addition to variations in the experimental situation used for training, a second factor may contribute largely to the limits found for animals' discriminatory capabilities. This factor is the extent to which animals are pretrained on shapes exhibiting gross differences along the same dimension as the shapes they will ultimately be required to discriminate. Thus Lawrence (1952) found that a group of rats trained to discriminate black and white cards and then transferred gradually to more and more similar shades of grey reached a higher level of performance on the two closest shades of grey used than a group given the same total number of trials on the two closest shades of grey from the outset of training. Although crucial experiments have not been performed it is likely that the same considerations would apply in shape discrimination. Saldanha and Bitterman (1951) have demonstrated the importance of training on a given dimension for the case of broad and narrow striations.

For these reasons it is practically impossible to fix the upper limits of the capacity for shape discrimination in animals, and this means that any approach to the problem of mechanisms which attempts to correlate the capacity of the organism with the total number of connections available in the system responsible for the classification is not very promising. A further implication is that, if we are going to use learning scores as an index of the difficulty of differentially classifying different pairs of shapes in a species, it is necessary to keep the learning situation constant.

The interaction between species and situation will be further emphasized in the following section on experimental training techniques: an attempt will there be made to lay down general principles of training, but their application to any animal will depend upon a knowledge of the habits of that animal. Thus, while it is a sound general principle that, in order to secure efficient learning of a discrimination, a response high in the animal's repertory should be used, the actual response chosen will vary from animal to animal (e.g. grasping in the monkey, pecking in the chicken, attacking in the octopus, jumping in the rat).

4. Experimental Techniques of Training

(1) *Multiple-Choice Discrimination*

In our present stage of knowledge, the easiest way to elicit useful information about the way in which shapes are classified by organisms would seem to be to train animals to discriminate between only two shapes at any one time. If animals are trained to discriminate between three or more stimuli at once, they must learn at least three distinct reactions—they cannot learn merely to approach one stimulus-object and avoid the other: these are the two responses most commonly employed where there are only two discriminatory stimuli. If the animal is learning to discriminate three or more stimuli at once, the stimuli may either be presented successively or simultaneously, and the discriminative responses learned may either be made directly to the stimulus-objects or to some other feature of the environment.

We shall discuss these four possibilities separately, and for simplicity we shall consider only three-choice situations, though the same considerations apply to all multiple-choice situations.

(i) Animals could learn to discriminate between three stimuli presented successively by being taught to make three discriminative responses to some feature of the environment other than the stimuli themselves: e.g. a rat might be trained to press selectively one of three bars according to which of three shapes it was presented with. Because of the lack of connection between the response and the shape, this would probably be difficult for most animals to learn (*v.* below). A special case of this method is known as the matching-from-sample technique: the animal reacts to one of three stimulus-objects which are themselves examples of the shapes to be discriminated, and which one it reacts to on a given trial is determined by presenting it with a further instance of one of the three shapes. In this variant of the situation there is a connection between the response and the discriminatory stimulus, namely the similarity between the sample exposed and the object to which the animal has to respond, and learning should be correspondingly easier. Successful discrimination learning has been obtained using this technique with pigeons (Ginsburg, 1957), monkeys (Harlow, 1943; Weinstein, 1941*b*) and chimpanzees (Nissen *et al.*, 1949), but learning is slow. Although the technique has not in fact been used to throw light on the relative discriminability of shapes, it could be so used particularly if combined with an analysis of errors made to different sample stimuli.

(ii) Successive discrimination may be combined with learning reactions made directly to the object, but three different reactions must be learned, e.g. moving the object to the right, moving it to the left, or picking it up according to which stimulus-object is presented. Because of the arbitrary nature of the response it may be doubted if such a method would lead to very quick learning in most animals. Thus the response most readily learned in a discriminatory situation seems to be some form of approach or avoidance (*v.* below); in the situation here envisaged the animal has to learn not only to classify the stimuli to be discriminated, but to differentiate between three responses which are arbitrary with respect to the situation. Wodinsky and Bitterman (1952) have employed this technique: they trained rats to select the left-hand, middle or right-hand card in a jumping stand where all cards bore the same stimulus pattern according to which of three stimulus patterns were present on a given trial. Although they used an easy discrimination, learning was slow.

(iii) The shapes may be presented simultaneously and the reaction made to some other feature of the environment than the shapes. This involves the same difficulties as in (i) above, and the additional difficulty that the discrimination must be a conditional one: i.e. the shape which is to determine the reaction will depend upon some further feature of the situation which must be discriminated, e.g. which shape occupies the right-hand position of the three.

(iv) The shapes may be presented simultaneously and the reaction made to the shapes themselves. In this situation the response can be made one of selectively approaching one of the shapes, but which shape is to be approached must be made conditional on some further aspect of the situation. Wodinsky and Bitterman (1952) used this situation successfully with rats where the figure to be approached was determined by the relative spatial positions of the figures. Which shape is to be approached may be made to depend upon some aspect of the stimulus situation other than the spatial position of the shapes in relation to one another, e.g. the animal might be trained to approach selectively one or other of the shapes according to

variations in the colour of the background. The learning of conditional responses of this sort has been studied by Harlow and others using monkeys (Harlow, 1943; Spaet and Harlow, 1943; Young and Harlow, 1943*a*, 1943*b*) and by Lashley (1938) (using two stimuli only) with rats. In these experiments it was found that animals took very much longer to learn to select a shape when the shape they had to select was conditional upon the background of the shapes than when they merely had to select consistently the same shape.

We have now summarized the main variations in the relationships of the discriminative responses to the stimuli to be discriminated in cases where an animal is trained to discriminate between three or more stimuli at once. There are few reports in the literature of the use of any of these methods with animals other than monkeys and chimpanzees: because in all cases something more than merely approaching or avoiding a stimulus-object has to be learned it may be doubted whether any of these methods are suitable for use with animals much lower in the phylogenetic scale than monkeys. Where these methods have been employed with other animals, only very easy stimulus discriminations have been used involving colour or brightness rather than shape (Ginsburg, 1957; Wodinsky and Bitterman, 1952). As will be shown below, where methods similar to those necessary in discriminations involving more than two choices are used in two-choice situations, they are normally found to result in slower learning than where the animal simply learns an approach-avoidance habit. Not only will the learning be slower but the variability of the scores is likely to be increased. This increase will result from either (*a*) the difficulty of learning differential responses if approach-avoidance habits are not used; or (*b*) the difficulty of discriminating between the additional cues which must be introduced if a conditional approach-avoidance habit is being taught. This additional source of variability is undesirable since it will make it more difficult to detect differences in performance due to variations in the actual shapes discriminated. For these reasons, and because where multiple discrimination is involved it may be more difficult initially to determine the dimension in terms of which animals are classifying the shapes, it seems best to use two-choice situations in order to elicit information on shape discriminability.

(2) *Two-Choice Discrimination with Multiple Stimuli*

In the last section, we discussed the case where an animal is taught to discriminate between more than two stimuli at once and indicated its disadvantages for eliciting information on the discriminability of shapes. It is possible, however, to use more than two stimuli and yet leave the discrimination essentially a two-choice one. This section will be concerned with the question of the advantages and disadvantages of using more than two stimuli in a two-choice situation. There are four ways of doing this:—

(i) We may present the animal simultaneously with several identical negative shapes and one positive shape. This is known as the "oddity method." The animal has to learn to approach the positive shape and avoid the negative shapes. Basically it has to learn not to select any members of one class of stimulus-objects and to select another class of objects, i.e., a dichotomous classification is all that is required: in the situation discussed in the last section a multiple classification was required because the animal had to learn a different reaction to each of three or more shapes. Because the classification is only dichotomous results are easy to interpret, and because the reaction can at the same time be made directly to the stimulus-objects and not be conditional on some further cue, this situation does not

suffer from the defects of those discussed in the last section. Smith (1936) found that where there were three negative stimuli and one positive, cats learned the discrimination faster in terms of trials than where there was one positive and one negative stimulus: however, the correction procedure was used and the total number of errors was greater with three negative stimuli than with one. Nissen and McCulloch (1937*a*) obtained similar results with chimpanzees using nine negative stimuli. In a further experiment (McCulloch and Nissen, 1937) they kept the positive stimulus-object always in one of two positions and only counted as errors selection of the negative stimulus-object in one of these two positions: with this criterion of error, total errors were less where nine negative stimuli were used than where only one was used. These results do not indicate what is possibly the main advantage of this method. In all these experiments, the criterion of learning was the attainment of a certain proportion of correct first responses over a given number of trials. Now if the positive stimulus-object can occupy *any* position, the probability of selecting the positive stimulus-object at least four times out of five trials by chance is approximately 0·2 where there is only one negative stimulus whereas it is 0·0005 with nine negative stimuli (cf. Fields, 1953). For this reason it appears likely that this method might greatly increase the reliability of the results for the same length of time spent in training, and possibly make it easier to determine the relative ease with which different shape discriminations are performed. It is claimed by Nissen and McCulloch that the reason why simultaneous discrimination problems involving several identical negative stimuli are easier than problems involving only one is that the unique positive stimulus stands out against a background of negative stimuli similar to one another. This, however, is at best a vague explanation. Perhaps a more precise way of putting this point is that given that positive and negative stimuli can be classified as distinct, it may be easier for some animals to learn both to react to the class of which there is only one instance exposed and to learn to react to one class of shape and not to the other, than merely to learn to react to one class of shape and not the other. The situation used by Nissen and McCulloch would allow the animal to learn both things concurrently.

In addition to the species mentioned above (monkeys, chimpanzees and cats), rats (Koronakos and Arnold, 1957) and pigeons (Ginsburg, 1957) have been trained using the oddity method. It is possible that some animals have a pre-existing tendency to select the odd shape out of a series of shapes. Meesters (1940) has demonstrated that sticklebacks and sunfish tend to select without training the odd shape out of four when presented either with three triangles and a vertical bar, or three vertical bars and a triangle. This may be a further reason for oddity learning being in general easier than matching-from-sample learning (for a direct comparison in pigeons, *v.* Ginsburg, 1957).

It has, moreover, been found that some animals can learn to select the odd stimulus-object even where the actual shapes presented are varied from trial to trial: for partial solutions of the generalized oddity problem, cf. Koronakos and Arnold, 1957 (rats); Boyd and Warren, 1957 (cats); Meyer and Harlow, 1949; Moon and Harlow, 1955; Young and Harlow, 1943*b* (monkeys); Nissen and McCulloch, 1937*b* (chimpanzees). If an animal could be trained to solve the oddity problem consistently, the possibility of a new technique for acquiring the sort of information here sought would arise. By exposing a variety of different shapes simultaneously and discovering which shape is selected by an animal trained to solve the generalized oddity problem, it might be possible to discover very quickly along which dimensions shapes are being analysed. The possibility of using this technique with monkeys has been demonstrated by Young and Harlow (1943*b*).

(ii) It would presumably be possible to train an animal to select one positive stimulus presented simultaneously with several negative stimuli which differed from one another. This technique does not in fact seem to have been used in training. It suffers from the disadvantage that it would not be clear how many categories the animal was employing, i.e. it might learn to select a limited range of stimuli resembling the positive stimulus and reject everything else or it might learn to classify each of the negative stimuli separately, and not to react to each of those categories. The technique would have the following advantage: by comparing the number of errors made on each negative stimulus during training, we could discover which of the negative shapes the animal most tended to confuse with the positive. For this reason this method might be worth trying.

(iii) and (iv) Just as it is possible to have more than one negative stimulus so it would be possible to have more than one positive stimulus. However, there is less to be said in favour of this, since it would decrease the reliability of the results over a given number of trials. This technique has not been employed either with several identical positive stimuli or with several positive stimuli differing from one another.

(3) *Successive* vs. *Simultaneous Discrimination*

The following question may be asked about two-choice situations: is speed of learning affected by whether both stimuli are presented simultaneously every trial or whether they are presented successively one on each trial? Several investigations of this problem have been undertaken with rats: unfortunately, investigators have usually varied the way in which the response is related to the stimuli as well as whether the stimuli are presented successively or simultaneously. A typical study is that of Wodinsky, Varley and Bitterman (1954): they trained rats on a Lashley jumping stand. One group was presented on each trial with two *different* cards (horizontal striations and vertical striations): this group learned to jump to one card irrespective of whether it was to the right or left. The second group was presented on each trial with two cards with *identical* patterns (i.e. both cards either contained vertical striations or horizontal striations): members of this group learned to jump to the left-hand or right-hand card according to which pattern was presented. It will be seen that under these conditions, the first group (simultaneous discrimination) learns to approach one stimulus-object and to avoid the other, whereas the second group (successive discrimination) learns to jump to the left-hand side if one set of striations is presented and to the right-hand side if the other set is presented. Thus in the successive situation what is learned is not simply to approach one stimulus-object, but to jump to one place if one pair of stimulus-objects is exposed, to another place if another pair of stimulus-objects is exposed: hence we would expect the successive discrimination to be more difficult to learn, as indeed it was. Two further groups of rats were trained on discriminations involving the same stimuli, one with successive and one with simultaneous presentation, but both groups were trained to respond differentially by jumping to windows in the jumping stand *other* than the windows in which the stimulus-objects were presented: i.e. for neither group was the discriminative reaction made to the stimulus-objects to be discriminated. Under these conditions the group trained on successive discrimination actually did better than that trained on simultaneous discrimination. The reason for this may be that what the groups were discriminating was horizontal stripes from vertical stripes (successive group) and horizontal stripes on left vertical on right from vertical stripes on left horizontal on right (simultaneous group): the latter task should be more difficult than the former since it involves *two* discriminations; one between

horizontal and vertical stripes and one between right and left. However this may be, it will be seen that when for *both* simultaneous and successive discriminations the response to be learned is not directly made to the stimulus-object, the superiority of simultaneous over successive training disappears.

The authors of the study cited do not themselves give this interpretation of their results, but a similar interpretation is mentioned as a possibility in a subsequent paper (Bitterman, Tyler and Elam, 1955) in which the results of the previous experiment were confirmed. The purpose of the original paper was to test the hypothesis that when stimulus cards were exposed near to one another configurational learning would occur and hence successive discrimination would be facilitated, when stimulus cards are exposed far apart (in the two outside windows of the jumping stand) animals would learn the component stimuli separately and therefore simultaneous discrimination would be facilitated. Unfortunately, in this situation the condition favouring configurational learning involves learning to respond to a different locus from the stimuli, while the condition favouring component learning involves learning to respond to the stimulus-objects themselves: thus it is not possible to separate the two effects completely and this difficulty is inherent in further experiments undertaken by Bitterman and his co-workers on this subject (Wodinsky and Bitterman, 1952; Turbeville, Calvin and Bitterman, 1952; Bitterman and Wodinsky, 1953). The fact that successive learning under conditions favouring component learning was better than successive learning under conditions favouring configurational learning can only be explained on the grounds that in the former situation the response was made to the stimulus-object whereas in the latter condition it was not. Although it is difficult to separate the effects of the two variables, Bitterman, Tyler and Elam (1955) present evidence that some configurational learning may occur in a simultaneous situation (*v.* below).

In two other studies (Bitterman, Calvin and Elam, 1953; North and Jeeves, 1956), it was found that simultaneous discrimination produced faster learning than successive where the response learned in the simultaneous situation was consistently to approach one stimulus-object irrespective of place, while that learned in the successive situation was to select a place (not a stimulus-object) according to which pair of stimulus-objects was exposed. In one further study (Grice, 1949), no difference was found in speed of learning under these conditions. Three other sets of results (Calvin and Seibel, 1954; Spence, 1952; Weiss and Bitterman, 1951) are mutually inconsistent: however, in these three experiments rats were trained to choose one of two alleys on the basis of whether a light was on or off, and it is not clear how far the response learned in the simultaneous situation was a simple approach response to the light: moreover, the fact that rats are reluctant to approach the brighter of two alleys confounds the results (Calvin and Williams, 1956).

It is necessary to cite some further studies which confirm that in a simultaneous discrimination situation where the animal has to select one stimulus-object and not the other, the response learned is in fact usually one of approaching one stimulus-object and avoiding the other, and not going left when one configuration of stimuli is exposed and going right when the other configuration of stimuli is exposed. It has been found that chimpanzees (Nissen, 1950) and monkeys (Miller and Murphy, 1956), having learned to select one member of a pair of stimulus-objects arranged side by side, will transfer to the same stimulus-objects arranged one on top of the other and *vice versa.* Thompson (1954) obtained a similar result in a situation which seems to favour configurational learning (whether a given stimulus-object was to be selected or not was determined by which of two further stimulus-objects it was presented with). Fields (1935) found that rats which had been trained to jump to one of

two cards continued to jump successfully when five cards were exposed simultaneously, i.e. they had learned to approach one card not to jump on the basis of the configuration of the cards exposed. North *et al.* (1958) showed that rats which have been trained to jump to an *erect* triangle when an erect and an inverted triangle are exposed on a black background and to an *inverted* triangle when the two triangles are exposed on striped grounds, continue to jump to the erect triangle on black if it is exposed with an erect triangle on a striped background. This again demonstrates that rats had learned to respond initially on the basis of the separate stimuli exposed, and not on the basis of the total configuration of stimuli. (Further evidence indicating that learning in a simultaneous situation is usually of either an approach or an avoidance habit will be presented below in section 5 (2).) Notwithstanding these results, the possibility of configurational learning occurring in a simultaneous discrimination with certain combinations of stimuli is a serious disadvantage of the method, and few investigators using the method have made appropriate tests to discover how far configurational learning was involved.

Thus in the evidence so far cited there is nothing to suggest that if the stimulus-response relationships are held the same for both successive and simultaneous discrimination learning there is any difference in the efficiency of the two methods. MacCaslin (1954), however, has demonstrated that if the stimuli to be discriminated lie close to one another along a single dimension (neighbouring shades of grey, and striations with small differences in width) there is a marked difference in the efficiency of the two methods. Under these conditions simultaneous training leads to much more rapid learning than successive, presumbably because of the difficulty animals have in remembering the absolute position of a stimulus on a single dimension: the simultaneous situation enables them to respond to the relative difference, and hence is superior. Since in most shape discriminations the stimuli differ widely along several dimensions, it is usually safe to use successive training for shape discriminations. The successive method is only less advantageous than the simultaneous if a response other than approach-avoidance is learned, but this is not a necessary feature of successive training. Although it has rarely been used with mammals there is one variant of the successive method which avoids this disadvantage: the animal can be trained to approach one stimulus-object when it is presented and not to approach the other. This method has been extensively used in the training of octopuses on visual discriminations and with this species it is more efficient than simultaneous training (Sutherland and Muntz, 1959). This method would appear to be one of the most suitable for investigating the discriminability of shapes: (i) Learning should be rapid because the response is made directly to the stimulus-object; variability of learning due to the difficulty of learning a response rather than the difficulty of discriminating the stimuli should be minimised. (ii) The possibility of configurational learning is eliminated: with some difficult discriminations this may be of considerable importance—e.g. in the Lashley jumping stand where the stimulus cards are next to one another, a rat might solve the problem of jumping correctly to one member of two sets of oblique striations where the striations run at 90° to one another by learning to jump to one side where the two patterns of striations taken together form a series of Vs with apex down, and to the other side where the two patterns form a series of Vs with apex up. (iii) The problem of position habits does not arise (*v.* below). (iv) As will be shown later, the results of transfer tests are easier to interpret with a successive discrimination situation of the type outlined than with simultaneous discrimination.

It should be mentioned that the method of successive discrimination training was in fact first employed by Pavlov (1927) using a classical conditioned response,

not an instrumental one. The response is first conditioned to one stimulus, and then extinguished to a second by presenting the latter without reinforcement while maintaining the response to the original stimulus by presenting that at intervals with reinforcement. Pavlov (1927) named this technique "differentiation training": unfortunately, there are no experiments which compare the efficacy of this method with methods involving the learning of an instrumental discriminative response. It is, however, certainly a method which might be used in the attempt to uncover information about the discriminability of shapes, but in the absence of experimental evidence it is impossible to say what are its advantages and limitations.

(4) *The Discriminative Response*

Since experiments done on the simultaneous versus successive learning issue usually alter the relationship of the learned response to the stimuli, it has been necessary to discuss this topic at some length in the previous subsection. It will be sufficient here to enunciate some further general principles.

(i) The discriminative response should be one that does not require elaborate motor learning. If it does, learning will take longer and the difficulty of the motor learning will contribute to the variability of the performance score and possibly conceal the variability due to differences in the difficulty of discriminating different pairs of shapes. One way of ensuring that elaborate motor learning is not required is to select a response already prominent in an animal's response repertory—e.g. pecking in chickens, grasping in monkeys, attacking in the octopus, snapping in fishes. If it is not certain that the response itself does not involve motor learning by the animal, it is advisable to train the animal to a criterion on the response before the discrimination training itself is started (thus rats are invariably pretrained to jump to open windows on the Lashley jumping stand—the fact that this is time-consuming and that elaborate precautions have to be taken to avoid the formation of position habits is a further disadvantage of this animal in this situation).

(ii) As already indicated the response which seems to ensure quickest learning is one of simple approach to or avoidance of the stimulus-objects. The response should be made as directly to the stimulus-objects as possible. Thus, Wodinsky, Varley and Bitterman (1954), in an experiment discussed above, found that, irrespective of whether the figures to be discriminated were presented simultaneously or successively in the jumping stand, learning was slower if the response had to be made to windows not occupied by the figures than if it had to be made to the figures themselves. Murphy and Miller (1955, 1958) found that monkeys trained in the Wisconsin General Test Apparatus learned very much more slowly if they had to react to a wedge six inches underneath the stimulus-object than if they had to react directly to the stimulus-objects themselves. McClearn and Harlow (1954) also using monkeys found that the further away the locus of the response from the stimulus-object to be discriminated the less rapid was learning. Learning was in fact less efficient when the separation of the locus of the response from the locus of the stimulus-object was as little as one inch. Jenkins (1943) obtained a similar result with chimpanzees. Schrier and Harlow (1957) found that monkeys discriminated more efficiently if the response consisted of removing only the part of the stimulus-object bearing the relevant discriminatory cue than if a larger object had to be moved not all features of which were relevant to the discrimination. Gellermann (1933*a*) was unable to obtain evidence of shape discrimination learning in chimpanzees until he changed his experimental situation and placed the stimulus patterns to be discriminated on the lid of the box to which the reaction had to be directed instead of on the side of the box. This factor is part of the drawback of the Yerkes-Watson

discrimination box: reactions are not made directly to the stimulus-objects, since the animal runs through an opening to one side of the positive object. It may also explain the lack of success of Field's second modification of this apparatus, in which the animal has to run beneath the shapes to be discriminated. Using such an apparatus Munn (1930*a*) failed to obtain shape discrimination learning in rats. In all other discrimination situations listed above the reaction is made as directly as possible to the stimulus-objects to be discriminated.

(iii) A criterion of response should be laid down which is easy for the experimenter to apply consistently, otherwise in determining which response was in fact made an experimenter may be unconsciously influenced by his own expectations. Most of the experimental situations used seem to satisfy this criterion, though it is seldom made explicit in reports of experimental work whether there were in fact any responses which were difficult to categorize with certainty. Unless recording is automatic, the classification of responses in the Grice discrimination box type of apparatus presents difficulty, since the response is one of approach to a door and is not always very clearly defined. The difficulty of categorizing responses with complete certainty is the most serious drawback of the situation used with octopuses.

(5) *Control of Other Cues*

Care must be exercised to ensure that the animal does not learn to perform a discriminative response by discriminating cues other than the visual cues we are interested in investigating. There are three precautions that can be taken. (*a*) We may be able to eliminate altogether some additional cues. (*b*) It is often possible to randomize the occurrence of such cues with respect to the occurrence of reward and punishment. (*c*) If the cue cannot be eliminated during training, then it is possible to test for whether it was in fact used or not in learning, by running tests after training and removing the cue during the tests. Illustrations of the use of these methods will be given in the discussion which follows on the sorts of cue it has been found necessary to control.

(i) *Visual cues connected with the stimulus-objects.* If the two shapes to be discriminated differ in features other than their shape, animals may make use of these additional cues in performing the discrimination. Some of the features of the stimulus-objects which need to be controlled if we are investigating shape discrimination are differences of brightness between the figures, differences in area, differences in the relationship of figures to background, etc. Thus Munn (1930*a*) showed that while rats, in a modified Yerkes apparatus, could discriminate between different shaped figures differing in brightness, they could not distinguish between shapes which did not differ in brightness and he criticizes Fields (1928, 1929) for failing to control this cue. It is possible to control against differences of brightness and area by using figures of equal brightness and area during training; in this case, however, different figures will usually differ in length of outline, and the possibility that this was used as a cue during training must be tested by transfer tests with figures of different lengths of outline from those used in training.

A special case of learning based on cues other than the ones we wish to investigate is where the animal discriminates between two shapes not in terms of the properties of the shapes as such but in terms of their relationship to the background. Fields (1932) found that rats which had learned to discriminate a white triangle from a white circle on black cards in a jumping stand with the apparatus painted black reverted to a chance level of responding if the apparatus were painted white so that the shapes were now seen inside a square black framework formed by the black card against the white colour of the apparatus. Despite this, Lashley (1938) used

figures whose angular width was over half that of the width of his cards, and though the cards were the same colour as the apparatus there were clearly defined contours round them formed by the angles of the apparatus. Thus it is possible that his finding that rats could readily discriminate a diamond from a circle though they could not discriminate a square from a circle is to be explained by their discriminating the triangles formed between the edges of the diamond and the edges of the card. In order to avoid discriminations being based on the relation between figure and background, it seems advisable to make the figure itself small relative to the distance between the figure and the nearest contours in the background. The training situation used with octopuses achieves this better than any of the other situations listed. One way of testing for how far the original discrimination was based on the relationship between the form and the background is to perform transfer tests in which this relationship is systematically varied: Neet (1933) found that relationship with the background was of some importance in the learning of a discrimination between a triangle and a circle by monkeys: chimpanzees were less affected by changes in the relationship between a form and its background (Gellermann, 1933*b*). The influence of the background will be considered further below (Part II, 3 (3)).

(ii) *Visual cues from the apparatus.* In simultaneous discrimination learning, unless the positions of the positive and negative stimulus-objects are varied in such a way that the positive stimulus-object occupies each position 50 per cent. of the time, animals could learn to solve the problem by selecting always the same position. In the jumping stand the card which is fixed (i.e. the negative card which cannot be knocked over by a jump against it) may offer a differential visual cue to the rat because it is pressed more tightly against the frame of the stand. It is often impossible to be certain whether such a cue has been completely eliminated during training, and it is desirable to run transfer tests after training with the cue eliminated —i.e. to leave both cards unfixed, and to find whether discrimination remains unimpaired. In simultaneous discrimination, because responses to the two stimulus-objects are followed by differential consequences, there is usually some cue, however minimal, other than the difference between the shapes used, which might be employed by the animal in selecting its response. Running transfer tests in which responses to the two stimulus-objects are not followed by differential consequences will serve to remove such cues.

(iii) *Cues received through another sensory modality.* These may be tactile, olfactory, taste or auditory cues. Some examples will make clear the sort of control which it is necessary to exercise. Fields (1929) trained rats to go through an opening cut in the shape of a triangle on its base and to avoid an opening cut in the shape of a triangle on its apex. The rats were then blinded and retested: they maintained as high a level of accuracy as they had attained immediately before being blinded. They had in fact solved the problem by discriminating tactile or kinaesthetic cues, and it is not certain how far if at all visual discrimination between the triangles had played any part in the performance before they were blinded. Where the stimulus-object is itself a food object a similar problem arises. Thus, McAllister and Berman (1931) trained cats to select circles of sausage meat and to avoid squares of sausage meat (stimulus-object as reward): the squares were coated with quinine on the underside. The criterion of a response was picking one of the shapes up in the mouth. The experimenters controlled the possibility that the discrimination had been achieved by using taste or olfactory cues by testing the animals with squares and circles of sausage meat without coating the squares with quinine: since performance was not affected it is reasonable to conclude that the discrimination had originally not been made in terms of these cues. Herter's "prong-training" of

fishes raises a similar problem. To ensure that the fish is learning the discrimination on the basis of the stimulus shapes and not through differential cues emanating from the two baits used (one edible, one non-edible), at intervals during training blocks of tests are inserted in which identical baits (both edible) are presented. In many instances tests revealed less accurate discrimination than training trials, indicating that some use was being made of cues emanating from the baits. However, with sufficient training it is possible to produce 100 per cent. accuracy of performance in tests with many different stimuli and in many different species of fishes (Herter, 1953).

(iv) *Cues emanating from the experimenter.* The experimenter may unconsciously provide the animal with cues which may help in achieving the discrimination through his own movements or his method of handling the animal. The most remarkable case on record of this is that of "Clever Hans" (Katz, 1937): Hans was a horse which was able to tap out answers to questions with its foot—it learned to regulate the number of taps given by discriminating slight movements of the head of the experimenter. One way to control against such cues is to isolate the animal from the experimenter (e.g. by use of a one-way vision screen, as in the Wisconsin General Test Apparatus). Another control is to run some transfer tests with a different experimenter from the one to whom the animal is accustomed (McAllister and Berman, 1931)—preferably an experimenter who does not know what to expect from the animal, so that he will not provide cues unconsciously. Any unexpected failure to obtain discrimination may also be used as evidence to show that the animal was not succeeding in other experiments by making use of such cues.

(v) *Serial effects.* A further type of cue which it is necessary to control is that which might be afforded to the animal if the changes in the arrangement of positive and negative stimulus-objects have any regularity. Thus in the Lashley jumping stand the position of the positive and negative cards should not be reversed on every trial, otherwise the animal may learn simply to alternate the side to which it jumps. Animals can not only be trained to alternate choices (Hunter, 1940) but in some circumstances they have a tendency to alternate in the absence of training (cf. Glanzer (1953) for a review of the subject). To control against a better than chance score due to either learning the sequence of changes in position or to the coincidence of an unlearned tendency to alternate (or to select always the same side which was the tendency found by Lauer and Estes (1955) in a jumping stand) with some non-random feature of the actual sequence of positional changes used, the sequence of changes introduced should contain no obvious regularities and should in any case satisfy the condition that positive and negative stimulus-objects occupy each position 50 per cent. of the time and the condition that from one trial to the next their positions are altered 50 per cent. of the time. If these conditions are fulfilled neither a tendency to alternate nor to select one side can produce a better than chance score. It might be thought that a completely random sequence would be the best possible sequence, but if it happens that the position of the positive stimulus-object remains unchanged in the random sequence for a series of trials this could result in the animal learning to select only that side, and this in itself might slow up subsequent learning of the discrimination. In fact it seems best to arrange that the sequence should fulfil the two conditions outlined above over each section of the series where the sections contain only about 10 or 20 trials. In addition the condition that the position of the positive card should not remain unaltered over more than three trials could be imposed. It is always possible to analyse the results to discover whether the animal has made use of such an arbitrary limitation on the serial order of changes of position. Thus if the animal does not select the

positive stimulus-object more frequently on the trials occurring *after* a run of three without change of position than on the trials occurring *before* a run of three without change of position, then it can be concluded that its selection of responses has not been influenced by learning this arbitrary limitation on the randomness of the sequence (cf. Sutherland, 1957*a*). Gellermann (1933*c*) has prepared sequences of trials which satisfy the conditions we have outlined. The same considerations apply to temporal sequences of stimuli in successive discrimination learning, though here the sequence will depend on the order in which positive and negative stimuli are given, not upon the sequence of positions occupied by the positive stimulus-object.

A further point connected with serial order is that if trials are given in close succession and the animal is not removed from the locality of the apparatus between trials, the motions of changing the stimulus-objects must be gone through on *every* trial, whether or not they are in fact changed, in order to prevent the animal from learning to vary its response from trial to trial in accordance with whether the experimenter changes or fails to change the stimulus-objects.

(6) *Control of Preferences*

It is worth repeating here a point made in connection with the selection of a species for investigating shape discrimination. It was there shown that if before discrimination training started an animal had a prior tendency to give the required response to one of the shapes to be discriminated rather than the other, it is not possible to determine the ease with which these shapes can be classified in relation to other pairs of shapes. To control against this possibility, when any given discrimination between a pair of shapes is being investigated, half of the animals should be trained with one shape positive, half with the other shape positive and the scores of the two different groups compared. In practice this condition has rarely been fulfilled.

(7) *Elimination of Transfer Effects*

If we are interested in comparing the ease of different shape discriminations then a different set of animals should be trained on each one: animals should not be trained serially first on one discrimination and then on another. There are two reasons for this: (i) Learning of later discriminations may be improved by the learning of earlier ones because the animal may learn what type of cue is relevant, e.g. it may learn to discriminate in terms of the shapes of the stimulus-objects not in terms of their spatial positions, etc. Improvement in speed of learning over a series of problems has been demonstrated in monkeys (Harlow, 1944*a*, 1944*b*, 1949), marmosets (Miles and Meyer, 1956) and in cats (Warren and Baron, 1956). (ii) Learning of subsequent discriminations may be slowed down or speeded up if animals classify the shapes involved in the later discriminations in the same way as in the earlier discriminations. A recent study by Dodwell (1957) provides a remarkable instance of this: he found that rats which had learned to select horizontal striations and avoid vertical striations selected a square and avoided a circle without any further training. Again this is a factor which has not been adequately controlled in many experiments: thus Lashley (1938), in seeking to establish the relative difficulty of discriminations involving different pairs of figures, pretrained most of his rats by teaching them to select horizontal striations and to avoid vertical striations.

(8) *Conspicuousness of Stimuli*

There is some evidence that the more the shapes to be discriminated have themselves the quality of an object, the more readily the discrimination is learned. Thus

Harlow (1945*a*, 1945*b*) found that monkeys discriminated more readily between isolated stimulus-objects than between similar stimulus-objects mounted on wedges. The reason for this may be that it is easier for the animal to isolate the stimulus-objects from their background when they are not attached to another object and can be moved independently of any other part of the environment, than when they are both mounted on similar wedges and can only be moved with the wedges (cf. Schrier and Harlow, 1957, quoted above). Harlow and Warren (1952) and Weinstein (1941*a*, 1941*b*) have shown that monkeys have more difficulty discriminating between planometric shapes (cut from $\frac{1}{4}$ in. plywood) than between stereometric shapes (cut from 2 in. wooden board). Herter (1930) presents evidence which suggests that some fishes (Golden Orfe) may learn to discriminate three-dimensional objects more rapidly than two-dimensional. Unfortunately, comparable experiments have not been performed with any other organism. However, it seems probable that the more the stimulus-object is separated from its background the more readily discrimination takes place, possibly because this may help to direct the animal's attention to the stimulus-object. Thus we might expect that rats would learn discriminations faster if the stimulus-objects were solid objects rather than two-dimensional patterns drawn on cards, if they were in a separate plane from the background, and if they moved independently of the background (cf. Sutherland, 1961*a*). Movement is a further determinant of attention. These factors have never been adequately investigated, but they are all present in the training situation used with octopuses which results in very rapid learning. It is in fact difficult to train octopuses to discriminate between stationary shapes, but part of the difficulty lies in training them to attack objects not in motion (Sutherland and Muntz, 1959). One further factor which is almost certainly of importance in directing attention is colour or brightness contrast with the background, and in fact experimenters have invariably taken care that good brightness contrast should exist between shape and background.

Thus it seems probable that by increasing the object quality of stimulus shapes and by increasing contrast with the background in the ways suggested, much more rapid learning could be obtained. Moreover, if a situation is used in which shapes compel attention in this way, the animal should learn more rapidly to orientate itself to the shapes, and the scatter of the results due to such learning should be reduced: if we are primarily interested in variations in the rate of learning due to differences in the discriminability of the shapes themselves this would be of considerable advantage.

(9) *Correction* vs. *Non-Correction Method*

In a simultaneous discrimination situation, where an animal makes an incorrect response the experimenter can *either* remove the animal from the experimental situation, make the alteration in position of stimulus-objects (if any) appropriate to the next trial, and proceed with the following trial *or* he can leave the animal in the situation without altering the arrangement of the stimulus-objects and allow it to make further responses until it makes the correct one. The former procedure is known as the non-correction method, the latter as the correction method. McKelvey (1956) found little difference between the two methods of training in terms of trials and errors in rats learning a brightness discrimination without punishment for wrong responses. Unfortunately, there are no systematic studies of the efficacy of these two methods in teaching *shape* discrimination: little difference in efficacy has been found where the two methods have been compared in situations involving the learning of *spatial* discriminations, and the direction of the difference varies with the

experimental situation used (Hull and Spence, 1938; Kalish, 1946; Seward, 1943). It is possible that in the jumping stand where position habits develop easily the correction procedure might have some advantage since it would tend to break up such habits—the rat having responded to the card in the wrong window is forced to go on responding until it selects the other window: it cannot obtain reward 50 per cent. of the time by jumping consistently to one window. Lashley in fact always used the correction procedure. Sutherland and Muntz (1959) found it essential to use a correction procedure in simultaneous discrimination training with the octopus, otherwise very persistent side preferences developed. On the other hand, the scoring of the correction procedure is slightly more ambiguous than the scoring of the non-correction procedure: in order to find whether an animal is performing above chance expectation it is necessary to count only the first response an animal makes on each trial; yet in the correction procedure different animals may vary in the number of incorrect responses they make on single trials, and this variation might influence their error scores, if only the first error on any trial is counted. On the whole, it would seem simpler to use the non-correction procedure except in situations where an animal has a tendency to develop a position habit. It should be noted that some animals in some situations are more liable to form position habits than others: Warren (1959*a*, 1959*b*) has shown that cats rely on positional cues more than monkeys.

(10) *Rewards and Punishments*

(i) It is difficult to lay down any general principles regarding the optimal strength of rewards and punishments. Where reward only is used, the strength seems to make little difference over the early part of learning: thus three studies (Maher and Wickens, 1954; McKelvey, 1956; Lawson, 1957) found no difference in the number of errors made by rats in learning simple discrimination habits (black-white and position discriminations) with different amounts of reward. Leary (1958) and Miles (1959) found amount of reward did not affect the performance of monkeys learning shape discriminations, whereas Schrier (1958) obtained better performance with larger rewards. In two further studies, one on monkeys (Schrier and Harlow, 1956) and one on rats (Schrier, 1956), it was found that increases in the amount of reward, though they do not affect error scores early in training, may produce a higher asymtote of performance later in training. This agrees with the results of numerous studies on the effects of differences in amount of reward on running times (e.g. Dufort and Kimble, 1956).

Systematic studies on how far introducing punishment as well as reward improves discrimination learning have not been undertaken. It seems possible that punishment has a decreasingly beneficial effect as one goes up the phylogenetic scale but the evidence is scanty. Very high levels of discriminatory performance can be obtained in monkeys without the use of punishment (Harlow, 1944*a*, 1944*b*, 1945*a*, 1945*b*, 1945*c*, 1945*d*), on the other hand, it is difficult to teach octopuses a discriminatory reaction without punishment (Sutherland and Muntz, 1959). While rats can be trained on simple discriminations without punishment (e.g. black-white (Grice, 1948*b*)), some form of punishment has usually been used in training them on more complex discriminations. Smith (1934*a*) actually found that cats learned a shape discrimination more quickly when punishment for wrong responses was omitted. Dodson's work (1917) on the learning of a brightness discrimination in cats suggests that the best performance is secured by using little punishment if the problem being learned is difficult, more if it is easy. Studies on experimental neurosis (e.g. Maier, 1949) again suggest that too much punishment may be detrimental to the learning of a discriminatory response.

It seems likely that there may be an optimal level of drive for the learning of a discrimination, and it is possible that this level varies inversely with the difficulty of the task as in the case of punishment (strength of punishment may itself operate partly by producing different levels of drive). Remarkably few studies have in fact been concerned with the effect of different drive levels on discriminatory performance. In simple discriminations (black-white and position) one study has shown no effect of drive level on error scores (Hillman *et al.*, 1953) while another showed a reduction in errors with increased drive (MacDuff, 1946).

At the moment all that can be done is to adjust the variables of amount of reward, strength of punishment and strength of drive by trial and error with a given species in a given situation: having found a level of all three which gives reasonably rapid learning, it is important to maintain them as constant as possible throughout any series of experiments in which we are anxious to use performance as an index of the discriminability of different pairs of stimuli.

(ii) The temporal proximity of reward and punishment to the discriminative response is an important variable. Perin (1943) demonstrated that the quicker reward followed on a discriminative response the more quickly the response was learned: if there is delay, then the presence of a secondary reinforcing stimulus in the situation assists learning (Perkins, 1947; Grice, 1948*a*), i.e. immediately after the animal has given a correct response, a stimulus should be given to signal that the response was correct. Some recent work (Levy, 1957) indicates that learning will be equally facilitated if a signal to serve as a secondary inhibitor is given immediately after a *wrong* response. In investigating the discriminability of shapes it is clearly desirable to give reward immediately after the correct response: this makes it unnecessary to introduce a secondary reinforcing stimulus which must itself be discriminated and involves further learning, thus increasing the variability of the results. Punishment should also be given as soon after the incorrect response as possible.

The spatial contiguity of reward and punishment to the stimulus-objects and to the locus of response is probably also important. Thus Jarvik (1956) found more rapid learning by chimpanzees when a food reward was placed inside the stimulus-object than when it was placed under the stimulus-object. Murphy and Miller (1958) have shown that monkeys' performance is improved if the reward is in spatial contiguity with the response or the stimulus-object; however, if the response was made directly to the stimulus-object, learning scores were unaffected by the position of the reward (cf. also Riopelle and Harlow, 1961). Thus although contiguity of reward to the stimulus-object does not always influence speed of learning, it certainly facilitates learning in some situations and it is clearly safest to place the stimulus-object and the reward as near to one another as possible. It seems probable that where an animal is being trained to avoid a stimulus-object by punishing approach to the object with shock, learning might be more rapid if the shock actually emanates from the object than if the shock is delivered to a part of the animal not actually in contact with the object. One of the reasons why early work on shape discrimination in animals gave such disappointing results may have been that in the Yerkes discrimination box the animal was rewarded a considerable time after making its choice and in a place which was in the opposite direction to the stimulus-objects between which it was choosing. In this respect the Lashley jumping stand is a considerable advance, and so was the modification of the Yerkes apparatus introduced by Fields, in which the food reward was given in a compartment behind the stimulus-objects. Sutherland (1961*a*) has tried feeding rats through the centre of the positive stimulus-object. The technique which secures closest spatial and temporal proximity between reward and response is, however, that of making the stimulus-object itself a food reward:

this technique has been used with fishes (Maes, 1930), chickens (Katz and Revesz, 1908; Revesz, 1924), cats (McAllister and Berman, 1931) and primates (Jarvik, 1953). This method ensures both that the response is made directly to the stimulus-object and that reward is temporally and spatially closely connected with the object and the response.

(11) *Spacing of Trials*

Verplanck (1942) found that rats learned a black-white discrimination more slowly where trials were too closely spaced. Two further studies on the rat (Thompson and Pennington, 1957; Pennington and Thompson, 1958) indicate that learning is fastest with a 3- to 4-minute interval between trials: performance was impaired if either shorter or longer intervals were used. Young (1960) found that when octopuses are learning a simple discrimination, it makes little difference to performance whether trials are given at 5-minute or hourly intervals. It is surprising how little work has been done on the effects of massing and distributing trials on error scores in a discrimination task: from other work on the effects of trial intervals, we may however conclude that to secure the most efficient performance trials should not be too closely spaced.

5. Transfer Tests

Attempts to discover the dimensions of shapes in terms of which they are analysed by animals raise further problems of method. One technique is to train an animal upon a shape discrimination and then to present further shapes having some properties in common with the original shapes and to discover how far the animal will give the same reaction to the new shapes as to the original ones. Some variables affecting the results of such transfer tests will now be discussed.

(1) *Rewards and Punishments*

In order to discover how far animals will treat new shapes as equivalent to those on which they were originally trained, it is necessary either to run one transfer test with many animals, or to give the same transfer test to a few animals repeatedly. The former procedure has never been adopted, perhaps because of the time which it takes to train a large group of animals upon a discrimination. In the latter procedure, the question of how far rewards and punishments should be given for making responses to the new shapes arises. If differential rewards and punishments are given, the animal may learn to make correct responses to the new shapes in the course of the transfer tests: it is then difficult to know how far differential responses given to the transfer shapes depend upon relearning and how far on classifying them in the way the original shapes were classified. Because of animals' ability to learn what to learn (Harlow, 1949), it is not even certain that a saving in trials to learn the discrimination between the new shapes necessarily means that the animal is classifying these shapes in terms of some properties they have in common with the original ones. It is possible to compare the relearning times for one pair of new shapes with another pair, and it might be supposed that if an animal learns a discrimination between one new pair of shapes more rapidly than between another, this will prove that the former pair have more elements in common with the original shapes than have the latter pair. Even this conclusion does not unequivocally follow, since it would only be true if two conditions are satisfied: (*a*) If the two new pairs are of equal difficulty in the absence of any prior discrimination training: this condition can be satisfied by further experiments on naive subjects with the pairs of shapes involved in the transfer tests. (*b*) It is possible that relearning with some saving might be attained if the properties that were common to the original

shapes and the pair of shapes used in the transfer tests were properties shared by the positive member of the original pair and the negative member of the new pair, and by the negative original shape and the positive new shape. Under some conditions it may be easier to reverse responses to two classes, than to learn to give responses to two further classes—monkeys can learn to reverse their responses to stimuli classified in a certain way in one trial (Harlow, 1949). We can test for this possibility by training two groups of animals on any new pair of figures introduced and making opposite members of the pair positive for each group: if there is a difference between the two groups it must then be the case that the new shapes which were positive and negative for the group giving higher performance will have properties in common respectively with the positive and negative members of the original pair, or more accurately that at least one of these shapes will have properties in common with the member of the original pair of the same sign. It follows then that the results of transfer tests where the possibility of relearning is admitted through differential use of rewards and punishments can only be unequivocally interpreted if very rigid controls have been employed. These controls have never in fact been employed in any experimental work. Giving differential rewards and punishments has one further disadvantage: if more than one set of transfer tests are given to any one subject, it will be impossible to say whether savings in performance in later tests are due to similarities between the further shapes employed and the shapes used in the original discrimination learning or to resemblances between the further shapes and shapes employed in earlier transfer tests.

Some of these disadvantages may be eliminated by not giving differential rewards and punishments in the course of transfer tests. Ideally both rewards and punishments should be omitted, but in order to maintain motivation it may be necessary to reward an animal every trial whichever shape it selects. The only disadvantage of the method of omitting differential rewards and punishments during transfer tests is that it may be a less sensitive indicator of stimulus equivalence than the method of using trials to relearning with differential rewards and punishments: in cases where the similarity between the original and transfer shapes is small an animal may cease to respond differentially—because of the lack of differential rewards and punishments—before it has given any evidence of treating the new shapes as partially equivalent to the original shapes. Thus both methods have their place in investigations of shape discrimination.

When differential rewards and punishments are not used in transfer tests, retraining trials with the original shapes should be interspersed between transfer tests. This has two advantages: (i) It helps to maintain the original discrimination. (ii) Performance on the retraining trials gives a base line from which to measure the amount of transfer to other shapes. Sutherland (1960*c*) has developed an index for amount of transfer, namely $\frac{T - 50}{O - 50}$ where O is the percentage of correct responses given on retraining trials and T is the percentage of times that a transfer shape is treated as equivalent to one of the original training shapes (i.e. the number of times it is selected if transfer is measured from the original positive shape, the number of times it is not selected if transfer is measured from the original negative shape). This index will have the value 1 where transfer is complete, zero where there is no transfer.

(2) *Approach-Avoidance Learning*

A mistake made by some early investigators was to suppose that if a new shape is substituted for the original positive in a simultaneous discrimination situation,

then a tendency for the animal to continue to select the new shape rather than the originally negative shape proves that the new shape is classified by the animal as similar to the original positive. This is not a certain inference since the animal may be selecting the new positive shape only because it is avoiding the original negative shape. That some animals do in fact learn to do this was demonstrated by Munn (1931*a*): of a group of four chickens trained to discriminate a cross (positive) from a triangle (negative) three showed a breakdown in discrimination when the positive stimulus was changed but continued to discriminate when changes were made in the negative stimulus; the fourth discriminated well when the positive stimulus was changed, but responded at chance level when the negative stimulus was changed. Three chickens had learned to approach the cross, the fourth to avoid the triangle.

Other investigators have demonstrated that different species in different situations may learn either to approach the positive shape, or to avoid the negative shape, or both: when they learn both they may have learned one habit more thoroughly than the other. In three experiments rats learned both to approach the positive stimulus-object and to avoid the negative (Fitzwater, 1952; Reetz, 1957; Sutherland, 1961*a*): when the positive stimulus was exposed with a neutral stimulus, rats ran to the positive about as often as they avoided the negative stimulus when that was exposed with a neutral stimulus. However, Weidensall (1912) using punishment found that rats learned to avoid the negative stimulus-object rather than to approach the positive. Other studies on a variety of animals—sheep (Seitz, 1951), an elephant (Rensch and Altevogt, 1955), mice (Reetz, 1957), carp (Schulte, 1957)—showed equal learning of approach to positive and avoidance of negative. Performance is, however, invariably reduced when either of the original stimuli is paired with a neutral stimulus. Menkhaus (1957) using hens, Herter (1940) using a stoat, and Thompson (1954) with monkeys, found better performance with positive stimulus alone than with negative alone, though some learning to avoid the negative had occurred. Warren and Kimball (1959) found that kittens had learned to avoid the negative stimulus-object rather than to approach the positive even though no punishment was used. Three studies with monkeys (Harlow and Hicks, 1957; Leary, 1956; Moss and Harlow, 1947) suggest that monkeys may learn more by failure to get reward on the negative object than by obtaining reward on the positive: these experiments were performed by pretraining with a single stimulus-object (either rewarded or unrewarded) and testing with two stimuli. The conditions which determine whether approach to the positive stimulus-object or avoidance of the negative shall be better learned have yet to be determined. The fact that one or other or both is usually learned is further evidence that animals tend to learn to react to the component stimuli in a simultaneous two-choice situation rather than to the total stimulus configuration (cf. sections 4 (3) and 4 (4) above).

It might seem that one way to avoid difficulties which arise from not knowing which of the original stimuli the animal has learned most about is to alter both negative and positive stimuli at once, but even where this is done and transfer occurs we do not know which of the new stimuli is being treated by the animal as equivalent to one of the original stimuli unless a careful series of further transfer tests is run.

These difficulties may be partially overcome by the use of fuller controls: (i) We can obtain some indication of how far learning has been approach learning, how far avoidance, by running animals with one shape only exposed and finding how often they approach it when it is the positive, how often they avoid it when it is the negative. (ii) If some animals are trained to approach one of the original shapes,

some to approach the other, any asymmetry in approach-avoidance learning will be revealed in the transfer tests by differences in the performance of the two groups. (iii) Sutherland (unpublished) has recently attempted to scale transfer shapes along the dimension involved in the initial discrimination by using a method of paired comparisons. Animals are shown every possible pairing of a battery of transfer shapes: a consistency test may then be applied to the results, and it may be possible to discover in this way whether the original shapes were being discriminated in terms of more than one dimension. This is the most thorough procedure, but is very time-consuming since in order to run one transfer test with each pair of shapes ${}^{n}C_{2}$ tests must be given where n is the number of transfer shapes used. Thus in order to scale 20 different transfer shapes at least 190 tests must be given with each animal. One final difficulty in giving transfer tests after simultaneous training is that animals may develop strong position habits on transfer trials which are not manifested on the interspersed trials with the original shapes.

If successive discrimination training is used, some of these difficulties are reduced. Since the animal must learn to approach one stimulus-object and not to approach the other, it is possible to treat the results on any transfer test by comparing the proportion of approaches to a transfer figure frequently selected with the proportion of approaches to the original positive figure, and the proportion of approaches to a transfer figure infrequently selected to the proportion of approaches to the original negative figure. In this way a direct comparison may be made of the degree of similarity between different transfer shapes and the original shapes, since the proportion of times each transfer figure is selected is independent of the number of times any *other* is selected (for examples of this method of giving transfer tests with octopuses *v.* Sutherland, 1957*a*, 1958*a*, 1958*b*, 1959*a*, 1959*b*, 1960*c*, 1960*d*). With this method it is less likely that animals will learn more about one shape than about the other since the shapes are exposed independently, and once again this possibility can be controlled by training half the animals with one shape positive, half with the other. The problem of side preferences in transfer tests does not arise. For these reasons, transfer tests seem to be easier to run and interpret in a simultaneous training situation than in a successive.

PART II. SURVEY OF EVIDENCE ON SHAPE DISCRIMINATION

It is the aim of the following sections to present a summary of the evidence on the discriminability of different shapes and the properties or dimensions in terms of which they are discriminated by different species. Throughout these sections the following words will be used in the sense indicated below:

"*Orientation*" will refer to orientation in the frontal parallel plane; differences in orientation are the result of rotating the same form about an axis at right angles to the frontal parallel plane. "Differences in *form*" refer to differences produced in the geometrical relationships of the contours of a figure other than differences produced by changes in orientation or by changes in size. "Differences in *shape*" refer to changes produced in the geometrical relationships of the contours of a figure other than changes in size. Thus a triangle and a circle differ in both form and shape, whereas a vertical and horizontal rectangle of similar side ratios differ in shape but not in form. This distinction was first made clear by Bingham (1914). "*Normal square*" refers to a square orientated with two contours vertical and two horizontal; "*diamond*" refers to a square orientated with contours at 45° to vertical and horizontal. "*Square*" is a figure which is square in form: both normal squares and diamonds are squares. It is difficult to classify systematically the different discriminations upon which animals have been trained, and the different properties of shapes in terms of which they may be discriminated. Hence, in what follows different aspects of the same experiment may be treated in different sections and some repetition is inevitable for the sake of clarity.

1. Discrimination of Orientation

(1) *Rectangles*

A number of investigators have shown that discrimination between vertical and horizontal rectangles is very readily learned by rats. Thus Lashley (1938) found that rats learned to discriminate between vertical and horizontal striations in fewer trials than were necessary for any of 18 other pairs of shapes. This rapid learning by rats of the discrimination between horizontal and vertical striations has been confirmed in many more recent investigations (e.g. Bitterman *et al.*, 1953; Sutherland, 1961*a*). In transfer tests Lashley found that there was complete transfer to a single horizontal versus a single vertical line, and almost complete transfer to interrupted lines provided the interruptions were not too large. This latter finding would seem to establish that original learning was not based upon discriminating the distribution of light over a single part of the cards exposed: thus rats had not learned merely to discriminate between the continuous white stripe towards the base of the card bearing the horizontal striations, and the alternation of black and white patches at the base of the card bearing the vertical striations. Rats would also transfer to zigzag lines provided the deviations from a straight line did not exceed the width of the striations.

Lashley reports that vertical and horizontal striations are more readily discriminated than oblique striations running at 45° to vertical and horizontal but at 90° to one another. He also found discrimination between horizontal striations and striations at 12° to the horizontal, but unfortunately the difficulty of such discriminations in relation to the discrimination of 45° lines is not reported. Lashley

used two further pairs of figures, which could only be discriminated by detecting the difference between opposite oblique lines: these pairs were N *vs.* И, and S *vs.* Ƨ. No rat succeeded in reaching the criterion of learning within 180 trials on either pair. It is impossible to be sure that it was the orientation of the oblique striations that was being discriminated where discrimination between cards bearing oblique striations was achieved: the cards were set very close to one another and where the cards were arranged \ / rats could learn to jump to one side on the basis of the lines on the two cards tending to form V figures, and with the arrangement / \ they might learn to jump to the other side on the basis of a series of Λ figures. The fact that the oblique discrimination could not be performed with N and И which were centred in the middle of the cards, and was performed very poorly where the striations were placed on a circular background, thus preventing them reaching the edge of the cards is some confirmation for this suggestion. It is to be concluded that vertical and horizontal striations are very readily discriminable by rats, and lines in opposite oblique orientations much less readily discriminable if indeed they are discriminable at all. The fact that rats exhibit a strong preference for the horizontal lines in the jumping box, apparently developed before the onset of training, makes the interpretation of these experiments difficult (*v.* above).

Karn and Munn (1932) found that dogs learned to discriminate between vertical and horizontal striations much more rapidly than between upright and inverted triangles. Nissen and McCullogh (1937*a*) taught chimpanzees to discriminate between horizontal and vertical rectangles, and between two opposite oblique rectangles. Performance was practically as good on the opposite oblique rectangles as on the vertical and horizontal, except that one animal failed completely with the obliques. Because of the lack of transfer tests and the possibility that the oblique rectangles may have been discriminated by using the direction of the apex formed by the two figures exposed simultaneously, this experiment is again difficult to interpret.

Herter (1929) showed that angel fish could readily learn to discriminate horizontal and vertical striations. Sutherland (1957*a*, 1960*b*) found that of some 50 different shape discriminations on which he has trained octopuses that between vertical and horizontal rectangles was the easiest; discrimination was not based upon any absolute lengths involved since octopuses would readily transfer to rectangles of different sizes and proportions from those on which they were originally trained (Sutherland, 1957*a*). Moreover, the discrimination between two opposite oblique rectangles proved almost impossible for octopuses to learn even after prolonged training. It should be noted that Sutherland used successive discrimination which eliminates the possibility of configurational learning (contrast the successful learning of opposite oblique striations by Lashley's rats where the possibility of configurational learning existed). He further showed that the discriminations between oblique and horizontal and between oblique and vertical were of approximately equal difficulty, and that both were more difficult than discrimination between vertical and horizontal (Sutherland, 1958*a*). Transfer tests indicated that animals were discriminating in terms of the relative extents of the shapes which lay in the vertical and horizontal planes.

(2) *Triangles*

Lashley (1930, 1938) found that discrimination between an upright and inverted triangle was comparatively easy for the rat (e.g. it was much more readily learned than the discrimination between a triangle and a square). However, there is evidence that the rat may learn the former problem by discriminating merely the base lines of the figures—thus Munn (1930*c*) found that after training on this problem rats

would transfer to cards on which a ^ and a horizontal line were drawn in the positions originally occupied by the figures. They would not transfer to cards bearing the figure V and a straight line at the top of the card. Fields (1929) obtained a similar result in a modified Yerkes apparatus: rats trained to choose an upright triangle in preference to an inverted one, showed poor transfer to the original positive figure exposed with a horizontal rectangle, and even after very prolonged further training only reached an accuracy of 85 per cent.: this again suggests that the original discrimination may have been performed with reference to the base lines of the original figures. Fields (1932) showed that having learned to discriminate between an upright triangle and a circle, rats were very sensitive to changes in the orientation in the triangle of as little as 10° as shown by reduction in accuracy in transfer tests under these conditions.

Karn and Munn (1932) found that dogs could learn the upright versus inverted triangle problem, and since they transferred with little loss of accuracy to a discrimination between two sets of three dots placed where the corners of the original figures fell and also to an upright versus an inverted V, they would appear to have been discriminating in terms of the whole figure and not merely the base line. Dogs took longer to learn this discrimination than one between vertical and horizontal striations. Harlow (1945*d*) found that monkeys could learn to discriminate between upright and inverted equilateral triangles, but that the discrimination was more difficult than that between a triangle and a square in spite of the similarity in base line of the latter two figures.

Herter (1929) trained three gudgeon to discriminate between two right-angled triangles, one with hypotenuse horizontal and at the bottom of the figure, the other with hypotenuse horizontal and at the top of the figure. The fishes learned rapidly and transferred to other pairs of triangles with apex down and apex up. Tested with a normal square and a diamond they selected the diamond whichever original triangle had been positive in training: Herter concludes that the original task had been performed by isolating the direction of the apex of the *positive* figure (i.e. apex up or apex down)—the diamond possesses this property in common with the original figure whether that figure was apex up or apex down, and is therefore selected in the transfer tests. Although this interpretation is not fully secure, it suggests a difference between the ways in which rats and fish discriminate these shapes. Rats seem to discriminate in terms of differences at the base line, whereas gudgeon may isolate the position of the apex of the positive figure. In both cases discrimination may depend upon isolating a part of the two figures which is sufficient to differentiate them.

(3) *Mirror-Images and* 180° *Rotations*

Upright and inverted triangles are both mirror-images of one another and also differ from one another by 180° rotations in the plane of the shape. A mirror-image of a two dimensional shape can be defined as the shape produced by rotating the shape through 180° about an axis which lies in the same plane as the shape, i.e. rotating the shape through the third dimension (in fact, in the experiments discussed here rotation was always about an axis lying in the horizontal or the vertical plane). A 180° rotation in the plane of the shape occurs when the figure is rotated through 180° about an axis which runs at right angles to the plane of the shape. The two operations are not equivalent for all figures: e.g. 180° rotation of F produces ∃, whereas the mirror-image of F is ⅁ or ⅂. Unfortunately, no experiments have been performed to discover whether, where the results of these operations differ, it is easier for an animal to discriminate shapes which differ by one operation than shapes

which differ by the other. As already pointed out, Lashley's rats could not discriminate between N and И, nor between S and Ƨ. They also failed to discriminate between ◎ and ◎ (Lashley, 1938). These pairs all consist of mirror-images but not of shapes rotated in their own plane. Kirk (1936) found that rats will discriminate F from ⅁ without undue difficulty: again these figures are mirror-images, but not rotations of one another in the plane of the figure. They differ from the other three pairs of mirror-images, however, in that the difference in the members of each pair can be specified by reference to only one of the two co-ordinates, vertical and horizontal: if the N shapes are scanned from left to right they produce the same output, if the F shapes are scanned from left to right F yields a large output first and then a small one, whereas ⅁ yields a small output followed by a large one. This point will be taken up again below.

More numerous experiments have been performed with shapes that are at the same time mirror-images and 180° rotations of one another. One general finding would seem to be that up-down inversion is more readily discriminable than left-right inversion. Thus Lashley found that the figures ⊏ and ⊐ were significantly more difficult for rats to discriminate than the figures ⊔ and ⊓. It is possible that the latter pair is easier for the rat because of a difference in the base lines not present in the former pair. No significant difference was found in the discriminability of the pair △ and ▽ and the pair ▷ and ◁, although one pair has a more marked difference in the base lines than the other. Harlow (1945*a*) showed that monkeys experienced less difficulty in discriminating between ⊤ and ⊥ than between ⊢ and ⊣. Bossom (private communication) has recently confirmed this finding in monkeys using several different pairs of up-down and left-right inverted shapes. Sutherland (1960*a*) found that octopuses discriminate more readily between up-down mirror-image ⊤ and ⊔ shapes than between right-left mirror-images (i.e. ⊣ ⊢ and ⊐ ⊏). Thus in all animals tested it has been found that it is more difficult to discriminate between figures which are reversed along the horizontal axis than between figures which are reversed along the vertical axis.

There is no evidence that figures which differ from one another merely by up-down inversions or by right-left inversions are more difficult to discriminate from one another than other figures of comparable complexity but exhibiting genuine form differences. Thus Lashley (1938) concludes that "The learning scores with the symmetrical figures do not significantly exceed those for non-symmetrical pairs of figures of the same order of complexity." Harlow (1945*a*) found that rhesus monkeys had more difficulty in discriminating eight pairs of mirror-images than certain pairs of other figures (e.g. triangle *vs.* square); when, however, one member of each pair of mirror-images was arbitrarily combined with one member of another pair of mirror-images, it was found that difficulty of discrimination was still as great as for the mirror-images themselves. Gellermann (1933*a*) found that one chimpanzee could learn to discriminate two crescents differing by an up-down reversal and two five-pointed stars differing by an up-down reversal as readily as certain other pairs of figures, e.g. a cross and a square. Learning, however, was so rapid with all figures that little difference between different pairs could have been revealed in the results.

Herter (1940) trained a stoat to select W and avoid L: the animal transferred readily to the pairs WM and ⅃ L, selecting W in the former instance and ⅃ in the latter. This establishes that the stoat can readily discriminate between both up-down and right-left mirror-images. The same worker (1929) trained two perch to discriminate between R and L. When the original figure (R for one fish and L for the other) was shown in transfer tests with a mirror-image or a rotation of the

FIGURE 1

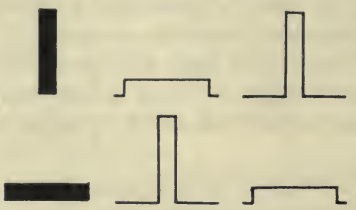
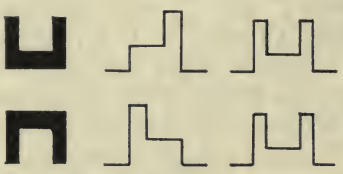
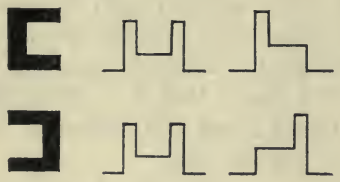
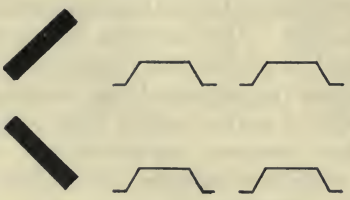
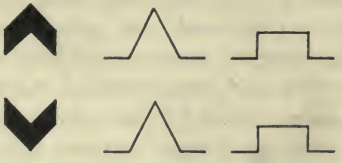
SHAPES HORIZONTAL PROJECTION VERTICAL PROJECTION	RATS	OCTOPUSES	FISHES
a 	1	1	
b 	2	3	
c 	3	4	
d 	3	Nil	
e 		Nil	

FIGURE 1—*continued*

SHAPE	HORIZONTAL PROJECTION	VERTICAL PROJECTION	RATS	OCTOPUSES	FISHES
f			Nil		
g					2
h					3
i				2	
j				2	

FIGURE 1

Discrimination and Orientation

Ten pairs of shapes are shown together with their horizontal and vertical projections. The numbers indicate the relative ease with which rats, octopuses and fishes are able to discriminate the pairs. Shapes very readily discriminable are labelled "1"; "2," "3," "4" indicate decreasing degrees of discriminability and "nil" means that animals were unable to discriminate between shapes.

same figure, the fish continued to choose the original positive figure 85 per cent. of the time: the figures he used in transfer tests were Я, Ꙗ, ⊿, ⅃, Γ, ⌙. Thus perch have no difficulty in discriminating either mirror-images, 180° rotation, or 90° rotated mirror-images of these figures.

Although, therefore, it is not true that all mirror-images are difficult to discriminate, it *is* true that some mirror-images are very difficult for some animals. Several instances have already been given of this, namely oblique striations and rectangles and the three mirror-image pairs used by Lashley (N И, S Ƨ, ◎◎). More recently, Sutherland (1959*b*) has shown that octopuses are unable to discriminate readily between an upright and an inverted V although under the same training conditions animals discriminated readily between upright and inverted ⌴ figures. The V figures in question were designed so that for both figures the horizontal and vertical extents of the figures were the same at each point on the vertical and horizontal axis. This is illustrated in Figure 1 which summarizes some of the data on pairs of mirror-image shapes from rats, octopuses, and fish. The horizontal and vertical projections are arrived at by counting total horizontal extents at each point on the horizontal axis. It will be seen that shapes giving the same horizontal and vertical projections as one another are difficult or impossible to discriminate (*d*, *e*, *f*.) Since all mirror-images which animals have difficulty in discriminating have the same horizontal and vertical projections as one another whilst those mirror-image figures which animals can discriminate readily differ in their projections, this may be the explanation of why some mirror-image figures are very difficult to discriminate. Sutherland (1959*b*, 1960*a*) has also compared the difficulty of discriminating mirror-image figures with the difficulty of discriminating the same forms differing from one another by a 90° rotation only. He found that an upright or inverted ⌴ was not easier for octopuses to discriminate from ⊏ or ⊐ than an upright from an inverted ⌴. On the other hand, V and > were readily discriminable in contrast to the pair V and Λ.

(4) *Miscellaneous*

In an interesting experiment, Hager (1938) found that minnows could discriminate between different *numbers* of striations very much more readily if the striations were vertical than if they were horizontal (cf. Fig. 1*g*, *h*). Discrimination was maintained when the breadth of the striations was varied. Inspection of Figure 1 will make it clear that when mirror-image shapes are used, animals tend to discriminate better between pairs differing in their horizontal projections (i.e. up-down mirror-images, Fig. 1*b*) than between pairs differing in their vertical projections (left-right mirror-images, Fig. 1*c*). Yet in the discrimination problems used by Hager, the pair of shapes differing in their vertical projections (vertical striations, Fig. 1*g*) is more readily discriminable than the pair differing in their horizontal projections (horizontal striations, Fig. 1*h*). Hager's finding could be explained if differences at the bottom of figures were more important for minnows than differences at the sides, but there is no evidence that this is true for fish, and Herter's (1929) results on discrimination between two triangles (*v*. above) suggest it is not true. Schulte (1957) found no significant difference in the rate at which carp learned to discriminate between broad and narrow vertical striations and broad and narrow horizontal striations. However, one fish out of three failed completely with the vertical striations and this suggests that the horizontals may have been easier. Sutherland (1960*c*) has compared the discriminability of the two pairs of shapes shown in Figure 1*i j*,

for octopuses.[1] This problem is similar to that set for Hager's fish, since what has to be discriminated is two points against one where the points are either vertical or horizontal. The two pairs of shapes were equally discriminable for octopuses, despite the fact that pair *j* differs only in horizontal projections and pair *i* only in vertical projections. However, in a subsequent experiment Sutherland (1961*b*) showed that horizontal rectangles of different lengths are more readily discriminable by octopuses than vertical rectangles of different lengths. Since the former differ along the horizontal axis and the latter along the vertical axis this is in line with results on mirror-image shapes differing along either the horizontal or vertical axis. The problem of why up-down mirror-images differing in their horizontal projections are more readily discriminable than right-left mirror-images deserves more attention than it has received. It is true that previous learning may play a part in this since a left-right reversal occurs whenever an animal goes to the opposite side of a shape, whereas the animal has to stand on its head while looking at a shape to produce an up-down reversal. Nevertheless, this does not explain what the discriminatory mechanism is, and light might be thrown on this by further experiments on non-mirror-image shapes which have differences either in the vertical or horizontal axis.

2. Discrimination of Form

(1) *Triangles and Circles*

The form discrimination which has been most studied is that between triangles and circles. Bingham (1913) claimed to have taught chickens this discrimination, though inversion of the triangle resulted in loss of the ability to discriminate and in a later experiment (1922) he found that where circles and triangles of different sizes were introduced discrimination was seriously impaired. He concludes that relative size differences of parts of the figures were involved in the discrimination. Katz and Revesz (1908) also trained chickens to perform this discrimination and Coburn (1914) trained a crow: in the latter experiment discrimination was unimpaired when a square was substituted for the triangle (in this case the negative figure). In a more elaborate study, Fields (1932) obtained discrimination between a circle and an upright triangle in the rat. Altering the relative sizes of the two figures did not impair performance. However, when the triangle was inverted, discrimination disappeared completely. In transfer tests with rotated triangles a horizontal rectangle was substituted for the circle: this substitution was made in order to meet the methodological requirement that to test for transfer to a figure substituted for the positive figure it is necessary to replace the negative figure at the same time to avoid transfer based merely on avoidance of the negative figure. In fact level of discrimination where the rectangle was substituted for the circle but the triangle was shown in its original orientation was 90 per cent.; discrimination with a triangle rotated 10° was 83 per cent., and with a 20° rotation 37 per cent. (i.e. less than chance expectation). This suggests that rats may have been discriminating partly in terms of the horizontal line at the base of the original positive figure: the rectangle has such a line, the 20° rotated triangle does not. Fields now tried to retrain rats to discriminate between a triangle in any orientation and a circle: whereas 580 trials had been necessary to reach a learning criterion of 90 per cent. in the original training, to reach 90 per cent. with any rotation of the triangle 500 further trials had to be given with left rotation, 240 with right rotation and 230 with an inverted triangle. Thus even by the criterion of relearning the amount of transfer from the original

[1] More recently Sutherland (in preparation) has shown that pair *j are* more readily discriminated than pair *i* by rats.

orientation of the triangle to new orientations is small. That transfer was not based merely on avoidance of the negative figure is shown by the results of substituting a cross, a square or a rectangle for the circle—discrimination between these figures and the rotated triangle continued at between 80 and 90 per cent. level of accuracy. In the Lashley jumping stand, then, it seems that rats do not generalize from one orientation of a triangle to another, but that they have to learn to attach the same reaction separately to the triangle in each orientation. Fields (1936*b*) found that raccoons which had learned to discriminate between an upright triangle and a circle would transfer to any orientation of the triangle exposed with the circle, and one raccoon was able to make this transfer when the rotated triangle was exposed with another figure. Fields also found that both rats and raccoons would transfer from equilateral triangles to right-angled or scalene triangle without relearning.

Smith (1934*b*) found that cats having learned a simultaneous discrimination between a triangle and a circle would transfer to other orientations of the triangle; transfer was still present though there was some decrease in accuracy when a square was substituted for the circle (the negative figure). Neet (1933) found that macaques having learned to discriminate an upright triangle from a circle transferred readily to other orientations of the triangle even when another figure was substituted for the circle. Andrew and Harlow (1948) also trained macaques on this task; they found only slight transfer to further figures, some of which consisted of rotations of the original triangle: however, since results for rotation are not presented separately it is not possible to say how accurate transfer was on the rotated figures. Having retrained monkeys on 50 new pairs of figures in which some elements of triangularity always appeared in the positive figure, they found that the monkeys now generalized to 50 further pairs of figures in which the positive figure always contained some property of a triangle. Seitz (1951) found that a sheep solved this problem readily but he did not give transfer tests with rotated figures.

In none of the studies so far cited was any attempt made to compare the difficulty of discriminating a triangle and a circle with the difficulty of discriminating other pairs of figures. Sutherland (1958*b*, 1959*a*) found that octopuses had as much difficulty in discriminating triangle from circle as in discriminating square from circle, and triangle from square.

(2) *Triangles and Squares*

Lashley (1938) found that it was more difficult for a rat to discriminate between a normal square and a triangle on its base than between a normal square and an inverted triangle: this is probably to be explained by the similarity of the base lines of the former two figures. He also found that a triangle on its base and a normal square were more difficult to discriminate than an inverted triangle and a triangle on its base. Since the latter two figures differ only in orientation whereas the former pair differ in form, this confirms that orientation is readily discriminated by the rat, at least in the jumping stand. Lashley (1938) also found that this discrimination was easier than that between a normal square and a circle.

Towe (1954) found that pigeons which had been trained to discriminate an upright triangle from a normal square would not transfer if the triangle were inverted. Transfer did occur if a diamond were substituted for the normal square and the original triangle presented. Since, however, the triangle was the positive figure for all birds this result cannot be interpreted to mean that a rotation of a square in itself produces a lesser difference for the pigeon than a rotation of a triangle. Towe was able to obtain excellent transfer where the sizes of the figures were varied independently, as well as transfer to outline figures and distorted figures (cf. Fig. 2*c*,

and Fig. 3*b*): thus the pigeon's original discrimination had not been based on reacting to differential distribution of light over parts of the figures. Munn (1931*a*) trained chickens to discriminate between a diamond and an upright triangle; transfer tests showed that discrimination was based wholly on the difference between the base lines of the figures.

Neet (1933) found that macaques which had learned to discriminate between an upright triangle and a circle would transfer to an upright triangle and a normal square substituted for the circle (the negative figure). They did not transfer to an upright triangle and a diamond: this suggests that a triangle and a diamond are more difficult to discriminate from one another than a triangle and a normal square.

Klüver (1933) trained monkeys to select a large square in preference to a smaller one: he found good transfer to two circles of different size, but poorer transfer to two triangles of different size. This seems to indicate that for the monkey there is a greater difference between a triangle and a normal square than between a circle and a normal square, and this is in agreement with Lashley's findings on rats.

Gellermann (1933*a*) found that chimpanzees which had learned to discriminate between an upright triangle and a normal square successfully transferred to inverted triangles and diamonds, though they tended to rotate the head before responding to the figures in the new orientation.

Meesters (1940) trained minnows and sticklebacks on a filled-in triangle on its base and a filled-in normal square. In transfer tests both figures were rotated through various angles. The fish exhibited reasonably good transfer with 10° and 20° rotation of both figures, they chose randomly with 30° rotation, and exhibited negative transfer with 45° rotations—i.e. they chose the rotated square more often than the rotated triangle when both figures were rotated through 45°, although they had been trained with the normal square as the negative figure. When an inverted triangle (60° rotation) was presented with a diamond (the original square rotated through 45°) the originally negative square was chosen 100 per cent. of the time. This would seem to indicate that the fish had learned to discriminate in terms of the difference between a point and a horizontal line at the top of the figures, a feature that differentiates the two training shapes. When the triangle is inverted it now possesses a horizontal line at the top (formerly the differentiating feature of the square), whereas the square rotated through 45° now has a point at the top (formerly the differentiating feature of the original triangle): hence the form that was negative in training is chosen in transfer tests under these conditions. The suggestion that fishes tend to discriminate by isolating the parts of figures where there is maximal difference between them is in line with other results on fishes quoted above, and again emphasizes the importance of orientation for many animals. Meesters also found that where either solid or outline figures were used in training there was good transfer to figures whose corners only were indicated and to the figures / \ and ‾; transfer to the figures / \ and | | was very poor and this again suggests that the presence or absence of the horizontal line at the top of the original square was the feature in terms of which the original discrimination was made (cf. Fig. 2*b*, iii, iv). Herter (1949, 1950) showed that a variety of different fishes were capable of discriminating between a triangle and a normal square.

Sutherland (1958*b*) found that a normal square and equilateral triangle were easier for the octopus to discriminate than a diamond and triangle irrespective of whether the triangle was on its base or apex. Whether the pairs of training figures had different bases (□ ▽, ◇ △) or different tops (□ △, ◇ ▽) did not affect their

discriminability. Pentagons orientated with base horizontal tended to be treated as the equivalent of the original normal square or diamond; and there was practically complete transfer to triangles rotated through 60°: this suggests that animals were not simply basing their reactions on the difference between bases or tops of the original figures. This result is in marked contrast to the findings obtained with fishes. There was no transfer at all when a diamond was substituted for the original normal square, nor when a normal square was substituted for the original diamond. Since successive training was used, transfer tests for triangles in different orientations and squares in different orientations were independent of one another. Complete transfer was found for shapes either twice or half the area of the originals. The poorer discriminability of triangles and diamonds than of triangles and normal squares is in agreement with Neet's finding in monkeys.

(3) *Squares and Circles*

Lashley (1938) found that rats had great difficulty in learning to discriminate a normal square from a circle—in fact 75 per cent. of rats failed to reach criterion within 180 trials. However, rats were able to discriminate between a diamond and a circle with much less difficulty. Munn (1931*b*) also found that rats were unable to learn to discriminate between a normal square and a circle. Dodwell (1957), however, found that rats could solve this problem very readily if they were first trained to discriminate between horizontal and vertical striations with horizontal positive, and if in the square versus circle training the square was made the positive figure. This suggests that the difficulty Lashley's and Munn's rats had in discriminating squares from circles was caused by failure to detect any difference between the two base lines, since once a rat has learned to jump to a horizontal line it will jump to the normal square and not to the circle with little further training. Experiments with other animals have not revealed any special difficulty in discriminating these figures. Thus Coburn (1914) found that a crow trained to discriminate between a circle and a triangle, still discriminated when the triangle was changed to a square. Smith (1934*b*) obtained the same result with cats, and Seitz (1951) with a sheep. Menkhaus (1957) found that chickens which had learned to discriminate between a square and a cross transferred well when a circle was substituted for the cross. These results imply that in all four species circles and squares can be readily discriminated. Rowley and Bolles (1935) found that white mice learned the discrimination between circle and square to a criterion of 75 per cent. correct responses over 30 trials in as few as 54 trials and would transfer to smaller figures. However, the experiment involved pushing open swing doors and there was no adequate control to ensure that the animals' performance had not been based on differential cues emanating from the locked and unlocked doors. McAllister and Berman (1931) showed that cats could solve the circle versus square problem: this experiment was adequately controlled. Animals had not been restricted during training to seeing the squares in only one orientation and they appeared to be able to perform independently of orientation, though it is uncertain how far they were learning the discrimination independently for each orientation during training.

It was shown in the previous section that evidence from transfer tests run by Klüver (1933) suggests that it would be easier for a monkey to discriminate between a triangle and a circle than between a normal square and a circle. Only Lashley and Klüver have found that animals have difficulty in discriminating between squares and circles and then only in the case of normal square and circle.

Pache (1932) presents evidence which suggests that frogs can discriminate as readily between a circle and a normal square as between a circle and a triangle.

Herter (1949) found that one pike readily discriminated between a circle and a square; otherwise this problem does not seem to have been used with fish. Sutherland (1959*a*) showed that octopuses could discriminate as readily between a square and a circle as between a circle and a triangle or a triangle and a square. He trained animals with both squares and diamonds and found no difference in the discriminability of these shapes from circles. There was no transfer if a square rotated through 45° was substituted for the square used in training. Moreover, two animals which were retrained with a square in the different orientation (one originally trained on a normal square the other originally trained on a diamond) took as long to relearn the discrimination with the rotated squares as they had taken to learn the original problem. After relearning it was found that they were then able to transfer to squares in any orientation. All animals showed good transfer to figures of sizes different from those used in original training.

(4) *Crosses*

Lashley (1938) found that rats readily learned to discriminate between + and a circle of equal area, between × and a rectangle, and between + and a triangle. The latter discrimination was found not to transfer to × and an inverted triangle. The learning of the discrimination between ⊢ and + was more difficult but once learned there was good transfer to ⊥ and ×. In contrast to Lashley's results, Reetz (1957) found that rats and mice that had learned to discriminate between + and normal square transferred almost perfectly when both shapes were rotated through 45°. Gellermann (1933*b*) found that chimpanzees could discriminate between + and a square and that performance was not upset by 45° rotation of the figures, although animals were observed to tilt their heads to one side. A sheep (Seitz, 1951) and an elephant (Rensch, 1957; Rensch and Altevogt, 1955) have been trained to discriminate between cross and square. The elephant transferred to the rotated cross exposed with a new shape.

Menkhaus (1957) performed a very thorough study on hens involving discriminations between square and +, × and diamond, and × and triangle. The animals showed excellent transfer when both figures were rotated. They also transferred well to outline figures and figures with discontinuous outlines. The animals did not, however, discriminate the cross in terms of two bars crossing one another: any shape with two bars present tended to be treated as a cross (e.g. ⌋). When the original cross was presented with two vertical or two horizontal bars there was almost no transfer.

Meesters (1940) trained minnows to discriminate between a black filled-in diamond and a black filled-in +. Both shapes were exposed against white square backgrounds whose height and width were only slightly greater than the height and width of the shapes. Transfer tests indicated that discrimination took place more in terms of the relation between the shape and its background than in terms of the shapes themselves. Thus transfer occurred wherever white triangles of the form ◸ ◹ appeared in the top left- and right-hand corner of the stimulus plaques; such triangles corresponded to the white bits left at the corners of the stimulus plaque by the original diamond. Moreover, when both figures were rotated through 45° (leaving the white background square in its original orientation), × was treated as equivalent to the original diamond—again presumably because of the presence of white triangles in the corners of the stimulus plaque when it bore the rotated cross.

Herter (1949, 1950) trained a variety of species of fish to discriminate between a circle and a cross: intra-species differences in learning times were so great as to

mask any inter-species differences that may have been present. Where in transfer test shapes of the form ✦ were exposed, they were treated as equivalent to the original + if exposed with a circle and as equivalent to the original circle if exposed with +.

(5) *Miscellaneous Shapes*

Boycott and Young (1956) found that octopuses could learn to discriminate between ⊏ and L, but only with considerable difficulty. Sutherland (1959*b*) found that octopuses could discriminate readily between M and >, less readily between Λ and >, and even less readily between M and Λ. Moreover, where animals had been trained on M and >, the substituted shape ≥ was treated as equivalent to >, and the substituted shape Λ was treated as equivalent to M (since successive discrimination was used, transfer tests were independent for the two shapes). The shapes were so designed that M and Λ had the same vertical and horizontal projections as one another, as calculated in the way described above (cf. Fig. 1). These results suggest that discrimination may be achieved by analysing the vertical and horizontal extents of figures, cf. the section on mirror-images above, though since some discrimination was found between M and Λ (which have the same horizontal and vertical extents as one another) octopuses must be able to take account of other properties of figures (perhaps in this case the extent to which figures are open or closed, i.e. have a high or low proportion of contour to area). This experiment, like many of the experiments with rats and fish, reveals the importance of the orientation of shapes: when a training form is rotated in a transfer test it may be treated as the equivalent of the *other* form used in training.

Herter (1929) trained two perch to discriminate between R and L: the R was positive for one fish, negative for the other. In transfer tests he showed that the fish trained with R positive had learned to react in terms of the presence or absence of a loop at the top right-hand corner of the figure, whereas the fish trained with L positive had been reacting in terms of the presence or absence of a horizontal stroke at the bottom right-hand corner of the figure. Once again we have an example of fishes solving a discriminatory problem by isolating the differentiating properties of shapes. Fisher (1940) obtained similar results in a study in which minnows were trained to discriminate the members of the following letter pairs UE, WL, WM, RB.

Herter (1940) performed a similar type of experiment with a stoat: the two letters on which it was trained were W and L. He gave a thorough series of transfer tests, from which two facts emerge. (*a*) The stoat had learned the orientation of the shapes: when W and M were presented in transfer tests it continued to select W (this contrasts with the results on *Octopus* reported above for V and Λ). (*b*) The stoat appears to have learned that there was a right-angle present in the L and a 45° angle present in the W. Thus when shapes of the form ⟋ and V were shown transfer was excellent if the two angles were respectively 90° and 45°. This was still true when the whole L was rotated so that the vertical bar had the same orientation as the left-hand vertical bar of the W. Even more remarkable was the finding that when both left-hand bars were at the same angle of inclination to the horizontal axis and one right-hand bar was at 75·5° to the left bar, and the other at 90° to the left, transfer was still very high (the right-angled figure was treated as L on 80 per cent. of trials). When the angles were made 45° and 67·5°, however, performance reverted to chance level.

Sutherland (1960*c*) trained octopuses to discriminate between the following eight pairs of figures: a normal square and a rectangle in four different orientations (vertical, horizontal, 45° to horizontal and 135° to horizontal); a diamond and a rectangle in the same four orientations. Separate animals were trained on each of the eight problems, and there was no difference in rate of learning. This establishes that octopuses do not discriminate between shapes primarily on the basis of the orientation of their contours: if this was an important feature of shapes for the octopus, we would expect the discrimination between a diamond and an oblique rectangle to be much less readily learned than some of the other discriminations. In an extensive series of transfer tests, Sutherland found good transfer to shapes of different sizes from the originals; rotated squares and a circle were treated as equivalent to the original square; there was only slight transfer from square to triangle; and moderate transfer from a square to an outline square. Perhaps the most interesting finding was that when a vertical rectangle was substituted for a horizontal, or a horizontal for a vertical there was a tendency for the rotated rectangle to be treated as equivalent to the original square rather than to the original rectangle. Most of these results can be explained if the dimension along which the original shapes were discriminated was that of the ratio of horizontal or vertical extent to the square root of the area of the shapes. Schulte (1957) trained carp to discriminate between a diamond and a vertical rectangle: this was an easy task for the carp (they learned it more quickly than, e.g. the discrimination between a cross and a circle). In transfer tests Schulte found only moderate transfer when the bottom halves of the shapes alone were shown and no transfer at all when shapes were rotated through 45° (i.e. a normal square and an oblique rectangle were presented). Once again this emphasizes the extreme difficulty most animals have in generalizing to rotations of a shape. Transfer to outline shapes was good, provided the outlines were made very thick.

Sutherland (1960*d*), as mentioned above, compared the discriminability of the two pairs of shapes shown in Figure 1*i*, *j*, for octopuses. There was no difference in ease of learning. In what follows the first member of each pair (as drawn in Fig. 1) will be referred to as a "closed" shape (it has no re-entrants), the second member of each pair as an "open" shape. Animals transferred well to shapes larger or smaller than the originals. Transfer was good when the closed shape was rotated, poor when the open shape was rotated. A circle and a square were treated as equivalent to the original closed shape. There was no transfer to a triangle. Crosses, rectangles, and ⊔ shapes tended to be treated as resembling the original open shape. The most remarkable finding was that when an outline open shape was presented it was treated as completely equivalent to the original open shape, but when an outline closed shape was presented there was zero transfer. These results suggest that animals may have been discriminating in terms of some such ratio as amount of contour to square root of area. It is interesting that in other species generalization to rotated shapes often occurs only where the shapes differ considerably in terms of this ratio (e.g. a cross and a square). Where they do not differ in terms of this ratio, rotating the shape usually upsets performance and this suggests that for these shapes discrimination may be based on an analysis along vertical and horizontal co-ordinates.

Warren (1953*a*) found that rhesus monkeys learned to discriminate as rapidly between irregular as between regular forms. They discriminated more rapidly between a regular and an irregular form than between two regular forms or two irregular forms. This suggests that one of the properties of forms which monkeys can discriminate is their degree of regularity.

3. The Properties of Shapes Discriminated

(1) *Size*

Animals which have learned to discriminate between two shapes have invariably been found when tested to show some transfer to identical shapes different in size from the originals. Many investigations have revealed readier transfer to figures larger than those originally used than to smaller figures even where visual acuity does not seem to have been a limiting factor. Fields (1931) found better transfer to larger shapes than to smaller ones amongst a group of rats which had been trained to discriminate between upright and inverted triangles. Rats trained on triangles and circles also tended to transfer better to larger than to smaller figures (Fields, 1932, 1935, 1936*a*). He also found (1936*b*) that raccoons trained on an upright triangle versus a circle showed good transfer when the figures were changed in size independently. The size of the negative figure (the circle) had little effect on the level of discrimination, but discrimination was noticeably less good when the positive figure was made smaller than when it was made larger. Towe (1954) found pigeons which had learned to discriminate between a triangle and a normal square showed good transfer when the size of the figures was varied independently. The birds performed slightly better (the difference does not appear to have been significant) with larger figures than with smaller, but they exhibited a preference for the larger figure when the size of each was changed independently. Menkhaus (1957) found that hens trained to discriminate between a cross and a square or triangle gave practically chance scores with smaller shapes. His shapes were nearly as large as the circular background against which they were exposed, and the original discrimination may have been performed in terms of some relationship between shape and background. Karn and Munn (1932) found that dogs transferred a discrimination between upright and inverted triangles to smaller figures, and Smith (1934*b*) obtained the same result with cats. Gellermann (1933*a*) found that chimpanzees which had learned to discriminate between a triangle and a square, transferred to both larger and smaller figures. Neet (1933) showed that macaques could transfer a discrimination between a circle and a triangle to figures of about 1/20th of the area of the original figures. Warren (1953*b*) found that the discriminability of regular and irregular forms for rhesus monkeys increased as the area of the forms increased from 0·9 sq. in to 5·4 sq. in. Dodwell (1957) found shapes of 13 sq. in. were more discriminable for rats than shapes of 2 sq. in.; transfer to larger shapes was made more readily than transfer to smaller.

Schulte (1957) found that carp transferred better to large shapes than to smaller. Sutherland has shown that octopuses readily transfer a shape discrimination to figures of different sizes from those used in training with a variety of different figures—rectangles, squares, triangles, circles, ⊔, ⩚ and ⋁ shapes, and the shapes shown in Figure 1*i*, *j*. Whenever the area of shapes was decreased by $\frac{1}{4}$ and increased by a factor of 4, transfer was significantly worse to small shapes than to large (Sutherland, 1957*a*, 1960*c*); where the size of shapes is changed by a factor of about 2, transfer is sometimes significantly worse to small shapes than to large (Sutherland, 1959*b*), but on other occasions no significant difference in amount of transfer to small and large shapes was found (Sutherland, 1958*b*, 1959*a*, 1960*a*, 1960*d*).

Thus in all species tested there is evidence of generalization when the size of figures is altered. This suggests that animals do not discriminate in terms of any absolute quantitative property of the figure (e.g. absolute lateral or vertical extent), but that they are analysing shapes in terms of relative properties which remain constant through size changes (e.g. the ratio between lateral and vertical extents, measures of extent divided by the square root of the area, ratio of contour to square

root of area, etc.). As Hebb (1949) has pointed out, the corners of a figure remain unaffected by size change. Although there is considerable evidence suggesting that generalization is easier to larger figures than to smaller, no attempt has been made to discover how far the size may be increased and discrimination remain unimpaired, much less to compare such a finding directly with the reduction in size of figures which may be made without impairing the level of discrimination. In order to establish with certainty the finding that transfer to larger figures is easier than to smaller it would be necessary: (i) To establish intervals of size which are equal for the animal (e.g. by choosing size intervals which the animal can learn to discriminate equally readily when performing a discrimination between sizes). (ii) To use a much greater variety of size of training figure than has in fact been used. (iii) To ensure that discrimination is always made from the same distance from the figures.

(2) *Outlines*

One type of transfer which animals seem to perform most readily is from filled-in to outline figures, or *vice versa*. Excellent transfer has been found from filled-in to outline figures with many different species and several different shapes: *rats*, inverted *vs*. upright triangle (Lashley, 1930; Munn, 1930*c*), cross *vs*. triangle (Lashley, 1938), cross *vs*. square (Reetz, 1957), circle *vs*. triangle (Fields, 1932); *mice*, cross *vs*. square (Reetz, 1957); *dogs*, upright *vs*. inverted triangle (Karn and Munn, 1932); *monkeys*, large *vs*. small square (Klüver, 1933); *hens*, square *vs*. cross, cross *vs*. triangle (Menkhaus, 1957); *pigeons*, triangle *vs*. square (Towe, 1954); *carp*, diamond *vs*. rectangle—provided the outlines were made sufficiently thick (Schulte, 1957); *minnows* and *sticklebacks*, triangle *vs*. square, large square *vs*. small square (Meesters, 1940). In all these investigations transfer was almost complete, i.e. animals continued to discriminate with at least 80 per cent. correct responses when outline shapes were shown. A few investigators have found less good transfer than this: Seitz (1951) found little transfer in a sheep from square *vs*. circle to outlines: Sutherland (1960*c*) found poor transfer to an outline square in octopuses after they had been trained to discriminate between a square and a rectangle. After learning to discriminate the open and closed forms shown in Figure 1*i*, *j*, octopuses gave complete transfer to an outline of the *open* form, but zero transfer to an outline of the closed form (Sutherland, 1960*d*). Very thick outlines were used in this experiment.

Very little work has been done on the question of how far a discrimination learned with outline shapes will transfer to filled-in shapes: Meesters (1940) found that minnows and sticklebacks would transfer as readily from outline to filled-in shapes as *vice versa*. Some of the above results and further results quoted below are summarized in Figure 2: in what follows letters and roman numerals in brackets refer to shapes shown in Figure 2.

Some investigators have measured transfer from filled-in shapes to shapes with discontinuous outlines, i.e. shapes with an outline composed of discontinuous dashes. Menkhaus (1957) found that hens transferred reasonably well to such shapes (*f*, ii; *g*, ii). Lashley (1938) showed that whether or not rats having learned to discriminate between horizontal and vertical striations would transfer to discontinuous striations depended on the size of the discontinuities in relation to the distance between the striations.

Other experiments have been performed in which transfer to figures with *dotted* (rather than dashed) outlines has been tested. Some transfer usually occurs but the level of performance is often low. Thus Meesters (1940) found a small amount of transfer in minnows and sticklebacks to a dotted triangle and square (*c*, v); Menkhaus (1957) obtained reasonably good transfer in hens with dotted cross and

FIGURE 2

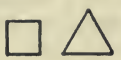
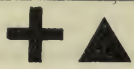
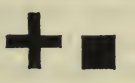
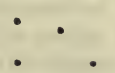
	TRAINING SHAPES	TRANSFER SHAPES	RATS	FISH	BIRDS	MONKEYS
a i			1 (Munn)			
ii			Nil (Munn)			
iii			Nil (Munn)			
b i				1 (Meesters)		
ii				2 (Meesters)		
iii				1 (Meesters)		
iv				3 (Meesters)		
v				Nil (Meesters)		
c i				1 (Meesters)	1 (Towe)	
ii					1 (Towe)	
iii				2 (Meesters)	2 (Towe)	
iv					Nil (Towe)	
v				3 (Meesters)		
vi				2 (Meesters)		
d i			2 (Fields)			
ii			2 (Fields)			
iii			2 (Fields)			
iv			2 (Fields)			
e i				Nil (Schulte)		
ii				1 (Schulte)		

FIGURE 2

Transfer to Outlines

The left-hand pairs of shapes are the original training shapes used and the right-hand pairs the transfer shapes used. Where transfer occurred animals treated the left-hand transfer shape as equivalent to the left-hand training shape and the right-hand transfer

FIGURE 2—*continued*

	TRAINING SHAPES	TRANSFER SHAPES	RATS	FISH	BIRDS	MONKEYS
f i			1 (Reetz)		1 (Menkhaus)	
ii					2 (Menkhaus)	
iii					3 (Menkhaus)	
iv					Nil (Menkhaus)	
v					2 (Menkhaus)	
g i			1 (Lashley, Reetz)		1 (Menkhaus)	
ii					2 (Menkhaus)	
iii					3 (Menkhaus)	
iv					Nil (Menkhaus)	
v					Nil (Menkhaus)	
h i				1 (Meesters)		1 (Klüver)
ii				1 (Meesters)		2 (Klüver)
iii				1 (Meesters)		Nil (Klüver)
iv						2 (Klüver)
v						Nil (Klüver)
vi				1 (Meesters)		
vii				1 (Meesters)		
viii				3 (Meesters)		
ix				1 (Meesters)		
i i			1 (Lashley)			

shape as equivalent to the right-hand training shape. The numbers are to be interpreted as follows: "1" means complete or almost complete transfer (i.e. a transfer index of between 85 and 100 per cent.), "2" moderate transfer (index 70 to 85 per cent.), "3" small but significant transfer (index between about 55 to 70 per cent.). In many cases estimates of the amount of transfer are only approximate. "Nil" indicates no significant transfer. Experimenters' names are shown in brackets.

triangle (*f*, iii), and dotted cross and square (*g*, iii), and Klüver (1933) found moderate transfer in monkeys which had learned to discriminate a small from a large square (*h*, iv). Gellermann (1933*a*) obtained no transfer in chimpanzees to a dotted triangle and circle: he used only six dots in each shape.

Where transfer has been tested with figures made up of dots placed only at the corners of the shape, transfer has usually been poor (cf. the Gellermann result quoted above). Pigeons failed to transfer to such a representation of a square and triangle (Towe, 1954, *c*, iv). Hens also failed where the original shapes had been cross and triangle or cross and square (Menkhaus, 1957, *f*, iv and *g*, iv). Monkeys (Klüver, 1933) also failed when a large and small square were each represented by four dots. Rats actually succeeded on this type of transfer problem after being given very considerable overtraining on a discrimination between triangle and circle (Fields, 1932, *d*, ii, iii). Lashley (1938) found good transfer in rats in the other direction: i.e. having learned to discriminate between two stimuli each of which was composed of two dots they transferred to lines drawn in the same orientation as the dot (*i*, i).

Another method of representing the corners of figures only is to show a set of angles missing out the sides of the shapes. Transfer tends to be somewhat better than where corners are represented only by dots. Thus hens and pigeons will transfer under these conditions moderately well (Menkhaus, 1957, Towe 1954, *c*, iii and *f*, v). However, this may have been less the result of recognizing the relation of corners to one another than of recognizing the orientation of lines since when the corners of a cross and triangle are represented in this way hens transfer (*f*, v), whereas when the corners of a cross and square are represented they do not transfer (*g*, v): the former pair of lines are in *different* orientations, the latter are in the *same* orientation. Meesters (1940) found that fish succeeded with a triangle and a square (*b*, ii; *c*, iii) whereas Munn (1930*a*) found that rats failed with upright triangle *vs.* inverted triangle (*a*, iii). Again the latter pair have lines in the same orientation as one another, although the reason for the rats' failure may have been that the horizontal line at the base of one triangle was destroyed.

Finally some work has been performed upon the question of whether animals will continue to recognize shapes when sides only are represented but the corners are omitted or when complete sides are omitted. Rats failed when only two sides of an upright and inverted triangle were shown (Munn, 1930*c*, *a*, ii), but succeeded after learning to discriminate a triangle and a circle when the corners of the triangle were omitted and the remaining shape exposed with three vertical lines (Fields, 1932, *d*, iv). It should be noticed that in the former instance, the base line of the triangle is destroyed, whereas in the latter it is preserved. In contrast to this, monkeys after learning to discriminate between a large and a small square showed good transfer when the base lines were omitted, no transfer when the lines at the tops of the squares were omitted (Klüver, 1933, *h*, ii, iii).

Meesters (1940) undertook the same experiment with minnows and sticklebacks and obtained transfer under both conditions (*h*, ii, iii). Meesters also found excellent transfer when the squares were represented by two vertical lines or two horizontal lines (*h*, vi, vii); when they each were represented by one line only, performance was much better when the line was horizontal than when it was vertical (*h*, viii, ix). This suggests that the fishes had learned more about the horizontal extents of the original squares than about their vertical extents and this agrees with Sutherland's (1961*b*) result on octopuses discriminating horizontal rectangles of different length and vertical rectangles of different length. Meesters (1940) obtained a similar finding after training minnows to discriminate a square from a triangle. Transfer was better when the square was represented by two horizontal lines than when it

was represented by two vertical lines (*b*, iii, iv; *c*, vi). Towe (1954) found excellent transfer in pigeons trained with an upright triangle and a normal square when the base line of each figure was omitted (*c*, ii).

It is difficult to summarize briefly the results of the studies quoted in this section, but certain conclusions seem to emerge. (i) The amount of transfer to figures with parts only of the outlines represented does not vary consistently with level on the phylogenetic scale. (ii) The excellent transfer found with most species to outline figures is important since it indicates that discrimination is not usually based either on areal or brightness differences between the original shapes. Moreover, it suggests that the distribution of brightness in the original stimulus pattern is not forming the basis of the discrimination. (iii) Transfer is as good or better where the sides of shapes only are represented as where the corners of shapes only are represented. (iv) Where the corners of shapes are represented by dots transfer is normally poor; where they are represented by angles the presence of *different* angles seems to be more important than the position of the angles relative to one another.

(3) *Background*

Fields (1932) found that rats, having learned to discriminate between a white triangle and a white circle exposed against a very extensive black background, reverted to a chance level of performance when the black background was reduced to a square surrounding the figure with the rest of the background painted white. It should be noted, however, that one rat continued to discriminate under these conditions, that no attempt was made to discover whether there would have been a large saving in trials to relearning with the remainder and that the complete change in the colour of the bulk of the apparatus may have caused emotional disturbances. Lashley (1938) found that varying the position of certain shapes, e.g. a triangle and a cross, in relation to the background did not affect transfer. Also, when two filled-in shapes had been learned, putting other outline shapes in the background surrounding the original shapes did not affect the discrimination. Unfortunately, after training with other shapes (e.g. diamond and circle), Lashley did not make tests to discover whether his rats had effected discrimination by making use of some differential properties of the figures in relation to their backgrounds.

Neet (1933) found that macaques were only very slightly disturbed by considerable changes in the shape of the background. His animals had originally learned to discriminate a triangle and a circle exposed against a square background which was only about twice the angular extent of the figures: substitution of a circular background impaired discrimination for three out of four animals but relearning was extremely quick. Further changes in the background, e.g. substituting a cross or a triangle as background, did not impair performance. Gellermann (1933*b*) found that wide changes in the shape of the background had no effect on the performance of chimpanzees which had been trained on a cross and a normal square.

Thus there is unequivocal evidence that higher mammals can discriminate shapes irrespective of their background even when the distance between the edge of the shape and the edge of the background is less than the distance between opposite edges of the shape. Unfortunately, there is very little evidence on this problem for lower animals.

(4) *Change in Relative Brightness of Figure and Background*

Fields (1932) found that rats which had learned to discriminate a white triangle from a white circle both exposed against a black ground, would not transfer to black figures on a white ground. His animals required more trials to relearn the

discrimination with the reversed figure-ground brightnesses than they had required to learn the original problem. However, two rats which did succeed in relearning to a criterion of 90 per cent. accuracy then transferred to other orientations of the triangle although they had failed to do so with the original figure-ground brightness relationship, and had received no differential training on orientation with the altered figure-ground brightnesses but only with the original figures. This successful transfer suggests that the mechanism for shape discrimination may be separate from that for brightness discrimination, and that the reason for the rats' original failure to transfer may have been that with change in brightness both figures may have been placed in different categories from the originals. Evidence is presented below to show that brightness and colour differences tend to predominate over form differences with some species. Lashley (1938) also found that there was no immediate transfer with rats where brightness differences between figure and background were reversed. However, Reetz (1957) obtained good transfer when brightness relationships were reversed with rats and slight positive transfer with mice. Smith (1936) showed that cats could transfer a discrimination between a triangle and a circle where figure-ground brightness relationships were reversed. Rowley and Bolles (1935) in a poorly controlled experiment found mice trained on a square *vs.* a circle were only slightly impaired in their performance when figure-ground brightnesses were reversed. Klüver (1933) obtained a similar result with monkeys which had learned a size discrimination, and Gellermann (1933*a*) with chimpanzees which had learned a form discrimination.

Towe (1954) found pigeons transferred excellently when brightness relationships were reversed, but Menkhaus (1957) found that hens reverted to a chance level of performance under these conditions.

Schulte (1957) found no transfer in carp when brightness relationships were reversed. Meesters (1940) found that minnows transferred perfectly from a discrimination between two white shapes to the same shapes in black and *vice versa*: the colour of the background remained unchanged. On the other hand, Sutherland (1957*a*, 1960*c*) found that under similar conditions octopuses give only slight positive transfer.

There is considerable evidence that some animals tend to classify stimuli more readily by colour or brightness differences than by shape differences. Thus Lashley (1938) found that a discrimination between black and white, and a discrimination between grey and black were both more readily learned by the rat than any of a wide variety of shape discriminations used. Warren (1953*b*) found that rhesus monkeys learned colour discriminations more readily than either form or size discriminations and discriminations in which the stimulus-objects differed in both form and size. He also found (1954) that, when original learning had been of stimuli which differed in colour, form and size, transfer was very much better to stimuli having the original colour differences but of the same size and form as one another, than to stimuli having the original size and form differences but of the same colour as one another. Cole (1953) found that monkeys trained to select a red square and avoid a blue triangle would select a red triangle in preference to a blue square, i.e. when the original colour and form were set in conflict they chose the colour that had originally been positive rather than the form. Macaques learn colour discriminations more rapidly than form discriminations (Harlow, 1945*d*). On the other hand, Seitz (1951) found that a sheep trained to discriminate a red cross from a green diamond transferred more readily to a red cross and red circle than to a red cross and green cross, i.e. the animal had learned to discriminate more in terms of shape than in terms of colour.

Similar experiments have been performed with fishes and the dominance of colour over form has usually been found to be less marked than with monkeys. Thus Schaller (1926) trained minnows to discriminate between a differently coloured star and rectangle and a differently coloured square and triangle. In tests the positive shape was combined with the negative colour, and the negative shape with the positive colour. Under these conditions whether the fish reacted in the transfer tests in terms of form or colour depended upon how great was the difference between the two colours used in training: thus when the two training colours were orange and red they reacted in terms of form, when they were dark brown and white they reacted in terms of colour. Again Horio (1938) found that carp showed a marked tendency to respond in terms of colour in transfer tests when they had been trained on red and blue and triangles and squares, but only a slight predominance of colour where the same shapes were used but the colours were violet and blue.

The experiments cited with fish reveal that the dominance of colour over form is a relative matter, and that it depends to some extent on the relative discriminability of the two forms and two colours used. Since a wide range of forms have been used in some of the experiments on monkeys, already cited, it seems safe to conclude that for the monkey at least there is a tendency to categorize in terms of colour differences in preference to form differences. It would be possible to pick form and colour differences which were matched for difficulty of learning in a given species, and then to test for whether one or other was predominant when both were present simultaneously in the two figures to be discriminated: if under these circumstances colour differences still determine responses, then considerably greater weight could be attached to the claim that colour differences predominate over form differences.

(5) *Parts of Figure*

By transfer to parts of the figure, we mean transfer which occurs when only some part of the figure is exposed: this differs from transfer to outlines or incomplete outlines in that where outlines or incomplete outlines of the figure are shown all parts of the original figure are represented incompletely. It is possible, however, to omit completely some part of the figure, and present in a transfer test only the remainder of the original, e.g. the base line only, the upper half only, the lower half only, etc. A second method of answering the question whether the original discrimination was based on discriminating properties of some part of the figures only is to show that *distorting* the figures in one part does not impair discrimination on transfer tests, whereas distorting the figures in another part does impair discrimination.

Much of the evidence on this problem has already been quoted above. Some of the evidence is summarized in Figure 3, and in what follows a letter and roman numeral in brackets will be used to refer to shapes in Figure 3. Munn (1930*c*) found that a rat which had learned to discriminate between an upright and inverted triangle would transfer when the base lines only were represented, whereas it would not transfer to the top parts of the triangles (*a*, i, ii). Lashley (1938) found that rats trained on a normal square *vs.* a diamond reacted correctly to the lower halves of the figures only and also to the interior lateral halves of the figures (i.e. the lateral halves next to the dividing line between the two cards); they did not transfer to upper halves, or exterior lateral halves (*c*, i, ii, iii, iv). It may be that the rat fixates the lower half of the figure because when it jumps it has to land towards the lower half, and it fixates the interior halves because it tends to jump towards the middle of the apparatus in order to cling to the dividing partition between the two figures if the jump is made to the wrong card. Dodwell (1957) succeeded in obtaining

FIGURE 3

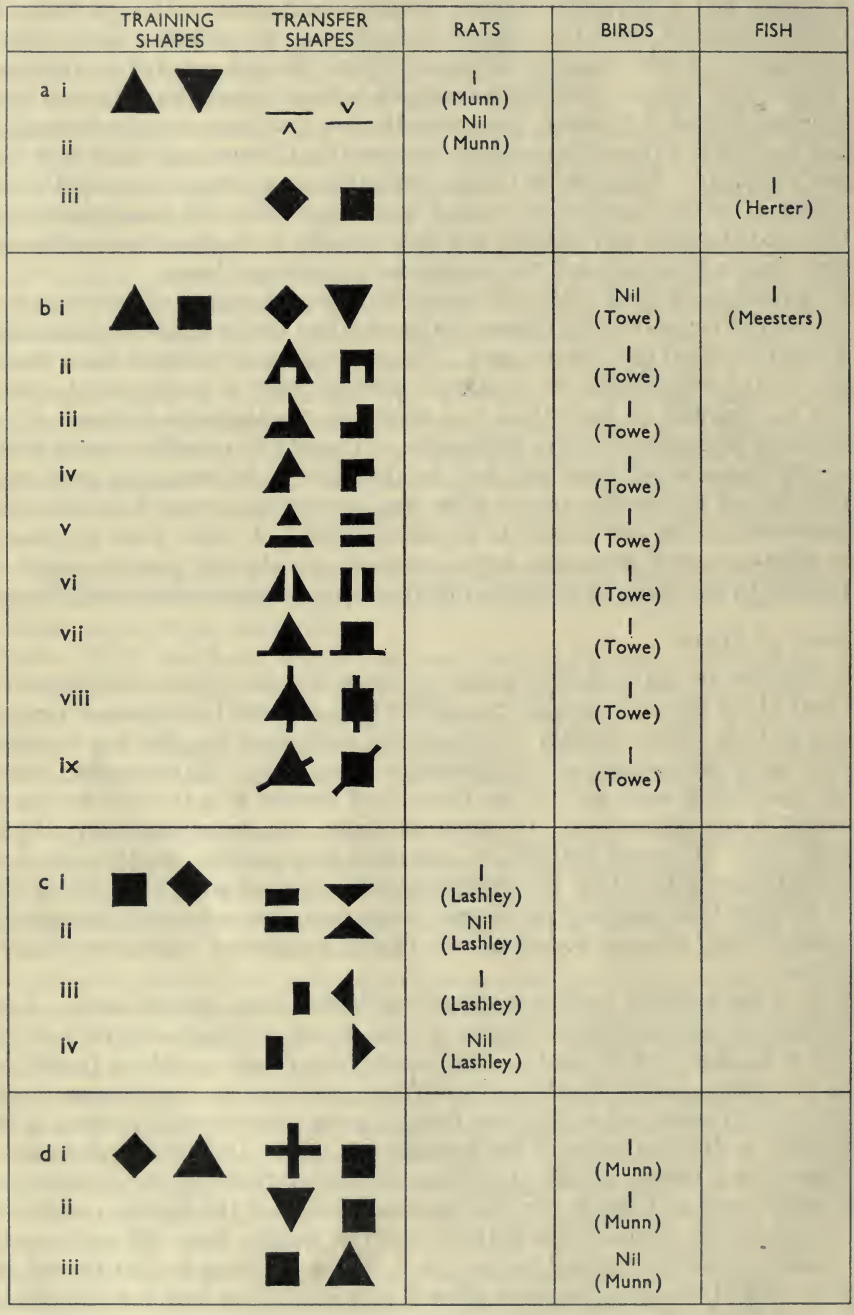

TRAINING SHAPES
TRANSFER SHAPES
RATS
BIRDS
FISH
a i
ii
iii
I (Munn)
Nil (Munn)
I (Herter)
b i
ii
iii
iv
v
vi
vii
viii
ix
Nil (Towe)
I (Towe)
I (Towe)
I (Towe)
I (Towe)
I (Towe)
I (Towe)
I (Towe)
I (Towe)
I (Meesters)
c i
ii
iii
iv
I (Lashley)
Nil (Lashley)
I (Lashley)
Nil (Lashley)
d i
ii
iii
I (Munn)
I (Munn)
Nil (Munn)

FIGURE 3—*continued*

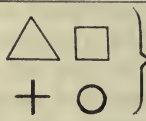
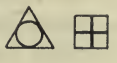
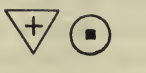
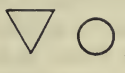
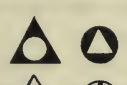
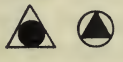
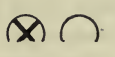
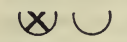
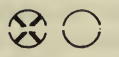
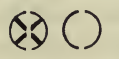
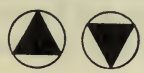
	TRAINING SHAPES	TRANSFER SHAPES	RATS	BIRDS	FISH
e i			1 (Lashley)		
f i			1 (Munn)		
g i			2 (Fields)		
ii			3 (Fields)		
h·i					2 (Schulte)
ii					2 (Schulte)
iii					2 (Schulte)
iv					3 (Schulte)
i i			3 (Munn)		

FIGURE 3

Transfer to Parts of Shapes

The conventions used are the same as in Figure 2.

discrimination between a normal square and a circle with a group of rats pretrained on horizontal and vertical striations. He found that the discrimination would transfer to an upright triangle and a circle but not to an inverted triangle and a circle. Once again the base line seems to be the part of the figure in terms of which discrimination was made. Further evidence that rats tend to discriminate in terms of the lower halves of the figures at least in the Lashley jumping stand is to be found in studies already cited (Fields, 1929, 1931).

Evidence about the tendency of other mammals to discriminate in terms of parts of shapes is largely lacking: since it has not been specifically sought, this does not mean that higher mammals do not to some extent share this tendency with the rat. However, the fact that some species can transfer readily to rotated figures (*v.* below) means that this tendency is much less marked for those species than for the rat. Similar tendencies seem to exist in chickens and fishes, though there is an important difference. Whereas in the jumping stand the rat seems to rely heavily upon differences in the bases (and possibly at the interior edges) of figures, chickens and fish seem in certain cases to discriminate in terms of the parts of two shapes which

most differentiate them irrespective of where these parts occur in the figures. Thus, Munn (1931*a*) found that two chicks which had learned to discriminate between a diamond and an upright triangle transferred to a cross and a square—the square which is a rotated diamond was actually treated as equivalent to the original triangle (*d*, i); they also transferred (*d*, ii) to an inverted triangle and a normal square (treating the inverted triangle as equivalent to the original diamond)—in this case both figures are rotations of the original figures and each figure when rotated becomes the equivalent of the other original figure. The discrimination broke down when there was the same distribution of light at the bottom of both transfer figures, e.g. when the original upright triangle was shown with a normal square. There seems to be no doubt that the chicks had solved the original problem by learning to discriminate properties of the lower halves of the figures: it should be noticed, however, that the main difference between a diamond and an upright triangle lies in their lower halves.

Several experiments have already been cited which suggest that fishes often discriminate by reacting only to isolated features which differentiate the shapes. Thus it has been found that perch discriminate between the letters R and L in terms of the properties of having a loop at the top and a horizontal stroke at the bottom right (Herter, 1929), and similar findings were obtained with other pairs of letters (Fisher, 1940) in studies on perch and minnows. When gudgeon were trained on an upright versus an inverted triangle, transfer tests showed that they had been discriminating in terms of whether there was or was not a point at the top of the figure (Herter, 1929, *a*, iii). Again, sticklebacks and minnows appear to discriminate between an upright triangle and a normal square in terms of the properties "point at the top" and "horizontal line at the top," and they show complete negative transfer if the original normal square is rotated to become a diamond and the original upright triangle is rotated to become an inverted triangle (Meesters, 1940, *b*, i). Schulte (1957) found that carp learned the tops and bottom halves of shapes equally well when there was as much difference between the top halves as between the bottom (*h*, i, ii).

(6) *Internal Distortions of Figure*

Several investigators have found that provided the outer parts of a figure are left unchanged, removing parts of the inside of the figure or inscribing other figures within the original figure have little effect upon discrimination. Thus Lashley (1938) trained the same group of rats to discriminate an upright triangle from a normal square and a cross from a circle: when the positive member of the latter pair was inscribed within the negative member of the former pair, and the negative member of the latter pair within the positive member of the former, the new figures were found to be equivalent to the former original pair (Fig. 3*e*, i): i.e. discrimination was based on reaction to the outer figures and was not impaired even where the animal had been trained to react in the opposite way to the figures inscribed within them. Munn (1931*a*) found that chicks which had learned to discriminate an outline inverted triangle with a cross inside it from an outline circle with a normal square inside it, transferred perfectly to the original outline figures both presented with no figure inscribed and presented with various other figures drawn within them (*f*, i). Fields (1932, 1935) found that rats which had learned to discriminate a filled-in triangle from a filled-in circle showed little decrease in accuracy where outline figures were presented with filled-in shapes inscribed in both of them (*g*, i): there was a marked decrease in accuracy where the original figures remained filled-in but had outline shapes circumscribed around them (*g*, ii). Munn (1930*c*) also found that rats' discrimination of

an upright from an inverted triangle was impaired when both figures were inscribed within circles (*i*, i). Thus it would appear that, at least for rats, making alterations to the immediate surround of the figure reduces transfer more than making alterations to the interior of the figure: altering the surround in the way specified has already been discussed in section (3). It is uncertain whether this result merely reflects a preference for large figures, which Lashley (1938) has shown to exist with rats over the range of size of figures used in the jumping stand. Towe (1954) found that pigeons' discrimination of an upright triangle from a normal square was very little affected by removing a part of either figure provided that not more than a quarter of the total area was removed (e.g. cutting out a square from the top right-hand corner, or from the centre of the base (*b*, ii, iii, iv), or removing a rectangular strip running vertically or horizontally through the figure (*b*, v, vi). Schulte (1957) found that discrimination in the carp was impaired when a horizontal strip was removed from the middle of the shapes; removal of a vertical strip reduced performance even more (*b*, iii, iv).

(7) *Distortion of External Parts of Figure*

By this is meant distortion of figures by adding portions to parts of the exterior of figures—this differs from change of background only in that the background is clearly separable from the figure, whereas where portions are added to the exterior of the figures the actual outline of the figure is changed. One way of stating this geometrically would be to define changes in background by limiting this to the addition of any lines which did not touch the outline of the figure at any two successive points (e.g. where a circle is circumscribed round a square), whereas in distortion of the external parts of a figure the change must be such that the lines added touch adjoining points on the periphery of the original figure. In only one study has this sort of change been investigated: Towe (1954) found that pigeons continued to discriminate between an upright triangle and a normal square when they were changed by the addition of a bar lying across the figures in various orientations (*b*, vii, viii, ix).

(8) *Changes of Orientation of Figure*

This particular change has already been discussed at some length in the section on the discriminability of shapes differing only in orientation. The evidence will be very briefly summarized here: the only established cases of a rat transferring a discrimination to rotated figures is that after being trained on ⊢ *vs.* + it transfers to ⊥ and × (Lashley, 1938). Reetz (1957) also found transfer to rotations of a square and a cross. Fields (1932) found that rats which had learned to discriminate between an upright triangle and a circle needed practically as many trials to relearning for other rotations of the triangle as had been needed to learn the original problem. No evidence has been produced that chicks can transfer to rotated shapes. Munn (1931*a*) found that chicks which had learned to discriminate between a diamond and an upright triangle, actually treated the originally negative form as positive and the originally positive form as negative when a normal square and an inverted triangle were shown. Towe (1954) found that pigeons' discrimination between an upright triangle and a normal square failed when they were presented with an inverted triangle and a normal square.

Fishes have been found not to transfer to different orientations of triangles and squares, but do transfer when a cross is rotated through 45° (Meesters, 1940). It seems that rats and fishes will only transfer to rotated shapes where the original shapes are differentiated by the degree to which they are open or closed, e.g. by their

"jaggedness," and this suggests that rats and fish may be able to discriminate in terms of this property. Octopuses transfer to different rotations of a triangle (Sutherland, 1958*b*), but do not transfer from normal square to diamond or *vice versa* (Sutherland, 1958*b*, 1959*a*). They will transfer to 180° rotations of ⩚ and V shapes but not to 90° rotations of these shapes (Sutherland, 1959*b*). They do not transfer to rotated rectangles (Sutherland, 1960*c*).

For animals higher up the evolutionary scale transfer has been found for rotated triangles (cats—Smith, 1934*b*, 1936; macaques—Neet, 1933; raccoons—Fields, 1936*b*; chimpanzees—Gellermann, 1933*a*). Herter (1940) found that a stoat transferred to rotations of W and L. It is remarkable that with this exception there is no study on mammals which adequately tests the equivalence of a square and a diamond, or of rotations of any forms other than triangles.

The evidence presented in the section on orientation suggests that discrimination of the same forms in different orientations is normally as easy for animals as discrimination of different forms.

4. Conclusions

It is impossible to provide a detailed summary of the evidence reviewed in this Part. Despite the number of experiments performed on shape discrimination few secure generalizations emerge: the reason for this is that few studies have been conducted systematically. Thus, the shapes used have been picked largely at random without any hypothesis in view; many experiments have simply established that a given species can discriminate between a given pair of shapes without attempting to compare the relative discriminability of different pairs. Despite this, the existing evidence raises some specific problems and an attempt has been made to indicate what these are and to suggest how they might be solved. It is perhaps worth summarizing some of the tentative conclusions which emerge from this review:—

(i) The rat often discriminates in terms of parts of the figures only (usually the base line).

(ii) Chickens and fishes also tend to discriminate in terms of parts of the figure, but discrimination is based rather on the parts which most clearly differentiate the figures, than upon the base lines.

(iii) Most lower animals do not readily transfer to rotated figures. Higher mammals and to some extent octopuses seem to rely more upon properties of the whole form and are less upset by changes in rotation.

(iv) Fishes, rats and octopuses may be able to discriminate in terms of the degree of openness of figures, i.e. in terms of differences in some such ratio as amount of contour to area. When figures differ markedly in this way, these animals can sometimes transfer to rotated figures.

(v) Animals can readily discriminate between different orientations of the same figure even when these are mirror-images. Right-left mirror-images are less readily discriminable than up-down.

(vi) Animals often have difficulty in discriminating figures whose vertical and horizontal extents at different points on the horizontal and vertical axis are the same. There is strong evidence that analysis of figures along their horizontal or vertical axes may play a major part in shape discrimination in many animals.

(vii) Studies which compare the discriminability of figures differing either in horizontal extent only or in vertical extent only yield conflicting results.

(viii) The rat tends to confuse normal squares and circles but this does not apply to other species tested.

(ix) Only higher animals transfer readily when the brightness relationship between figure and background is changed.

(x) Internal distortions of figures have less effect on discrimination than changes in the immediate surround of the figures.

(xi) All animals hitherto tested readily transfer to figures of different size: transfer tends to be better to larger figures than to smaller.

(xii) Transfer from filled-in to outline figures and *vice versa* is good. In addition, animals often transfer to figures with broken outlines: the tendency to do so does not appear to correlate with position on the phylogenetic scale.

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SUBJECT INDEX

A

Accommodation, 7, 10.
Animals,
  Cats, 16, 22, 24, 26, 28, 30, 40, 42, 46, 52, 58.
  Chickens, 9, 11, 20, 28, 30, 39, 41, 42, 43, 46, 47, 50, 55, 56, 57.
  Chimpanzees, 14, 15, 16, 18, 20, 22, 27, 33, 35, 41, 43, 46, 50, 51, 52, 58.
  Crows, 6, 39, 42.
  Dogs, 7, 9, 33, 34, 46, 47.
  Elephants, 8, 30, 43.
  Fishes, 9, 12, 16, 20, 22, 23, 25, 28, 30, 33, 34, 35, 36–37, 38, 39, 41, 42, 43, 44, 45, 46, 47, 50, 52, 53, 55, 56, 57.
  Frogs, 42.
  Hens *v. Chickens*.
  Marmosets, 24.
  Mice, 30, 42, 43, 47, 52.
  Monkeys, 5, 8, 10, 13, 14, 15, 16, 18, 20, 22, 24, 25, 26, 27, 29, 30, 34, 35, 40, 41, 42, 46, 47, 50, 51, 52, 53, 58.
  Octopuses, 6, 9, 12, 19, 20, 21, 22, 25, 26, 28, 31, 33, 35, 36–37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 50, 52, 58.
  Pigeons, 14, 16, 40–41, 46, 47, 50, 51, 52, 57.
  Raccoons, 12, 40, 46, 58.
  Rats, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 32, 33, 34, 35, 36–37, 38, 39, 40, 42, 43, 46, 47, 50, 51, 52, 53, 56, 57, 58, 59.
  Sheep, 30, 40, 42, 43, 47, 52.
  Stoats, 30, 35, 44, 58.
Approach—avoidance (*cf. responses*), 13, 17, 18, 19, 20, *29–31*.
Area (*cf. Properties of shapes discriminated: area*), 21.
Attention, *24–25*.

C

Conditional Discriminations, 14–15.
Configuration *v.* component learning, 18, 19, 33.
Correction *v.* non-correction method, 16, *25–26*.
Cues, control of, *21–24*.

D

Discriminable properties of shapes *v. shapes, properties discriminated.*
Distribution of trials, *28*.
Docility, *10*.
Drive, 27.

E

Emotionality, 10.
Error scores, 5.
Experimenter, 21, 23.
Exploration, 6.
Extinction, 5, 6.

H

Habituation of response, 6.
Habituation to situation, 10.

J

Jumping stand, *8*, 11, 13, 20, 21, 22, 26, 27.

K

Kinaesthetic cues, 7, 11.

M

Matching from sample, 14, 16.
Multiple-Choice Discrimination, *13–15*.
Multiple stimuli, *15–17*.

O

Oddity learning, 15–17.
Olfactory cues, 22.

P

Preferences between shapes, *11–12*, 24.
Pretraining, 8, 10, 13, 20.
Properties of shapes discriminated *v. shapes, properties discriminated.*
Position Habits, 8, 20, 23–24, 26.
Punishment, *26–27*, *28–29*.

R

Reaction times, 5–6.
Responses, discriminative (*cf. approach-avoidance*), 13, 14, 15, *20–21*.
Rewards, *26–28*, 28–29.

S

Shapes discriminated,
  Circles, *39–40*, 41, *42–43*, 44, 45, 46, 47, 51, 52, 55, 56, 59.
  Crosses, 40, 42, *43–44*, 45, 46, 47, 50, 51, 52, 56, 57.
  Diamonds *v.* squares.
  Mirror images, 33, *34–38*, 39, 58.
  Open and closed, 37, 38, 39, 45, 47, 57–58.
  Orientation, *32–39*.
  Pentagons, 42.
  Rectangles, *32–33*, 39, 40, 43, 45, 46, 47, 53, 58.

Squares, 40, *40–43*, 43, 45, 46, 47, 50, 51, 52, 53, 55, 56, 57, 58, 59.
Stars, 35, 53.
Striations, 32–33, 38, 42, 47, 55.
Triangles, *33–34*, 35, *39–42*, 42, 43, 45, 46, 47, 50, 51, 52, 53, 55, 56, 57, 58.
B, 44.
E, 44.
F, 35.
H, 43, 57.
L, 35, 44, 56, 58.
M, 35, 44, 46, 58.
N, 33, 35.
R, 35, 44, 56.
S, 33, 35.
T, 35.
U, 35, 38, 44, 45, 46.
V, 38, 44, 46, 58.
W, 35, 46, 58.
Shapes, properties discriminated,
Area, 33, 39, 40, 42, 43, 45, *46–47*, 57, 59.
Background, 21, 22, 43, 46, *51*.
Base lines, 33–34, 35, 38, 39, 40, 41, 42, 45, 50, 53, 55, 56, 58.
Brightness differences between parts of figures, 21, 32, 41, 51.
Brightness and colour of figure in relation to background, *51–53*, 59.
Broken figures, 32, 43, 47, 59.
Contour, ratio of to area, 44, 45, 57–58, 58.
Corners, 34, 41, 47, 48–49, 50, 51.
Dots, 34, 47, 48–49, 51.
External distortions of figure, 57, 59.
Horizontal and vertical analysis, 33, 35, *36–38*, 39, 44, 45, 58.
Internal distortions of figure, *56–57*, 59.
Isolation of differentiating features of figures, 34, 41, 44, 56, 58.
Outline figures, 40, 43, 45, *48–51*, 56, 59.
Parts of figure (*cf. base lines* and *isolation differentiating features*), 53–56.
Rotated figures, 35, 38, 39, 40, 41, 42, 43, 44, 45, 56, *57–58*, 58.
Sides, 48–49, 50, 51.
Symmetry, 35, 45.
Simultaneous *v.* Successive Discrimination Training, 13–15, *17–20*, *30–31*, 33.
Stimulus objects,
Conspicuousness of, *24–25*,
And locus of reward, 27–28,
And response, 20–21.

T

Tactile Cues, 7, 11, 22.
Taste Cues, 22, 33.
Transfer tests, methods, 6, 7, *28–31*.
Transfer tests, results *v. shapes, properties discriminated.*
Trials, sequence of, 23–24.

W

Wisconsin General Test Apparatus, *8*, 11, 20.

Y

Yerkes-Watson Discrimination Apparatus, 7, 12, 20, 21, 27.

① 181-31

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